

The University of Chicago

THE GEOLOGY OF
SOUTHWESTERN IDAHO

A PART OF THE DISSERTATION SUB-
MITTED TO THE GRADUATE FACULTY
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

By
VIRGIL RAYMOND DREXEL KIRKHAM

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REVISION OF THE PAYETTE AND IDAHO FORMATIONS¹

VIRGIL R. D. KIRKHAM
Lansing, Michigan

ABSTRACT

The history of the Payette and Idaho formations and their place in the literature is reviewed. Previous to 1928 the formations were mapped as a unit and undifferentiated. Evidence is presented which shows that the true Payette formation is exposed only on the flanks of the downwarp which comprises the great Snake River plains. Its characteristic occurrence is between two great lava extrusions. It has a characteristic lithology and a flora of Miocene age. The Idaho formation occupies the surface over much of the plains area and was formerly referred to as Payette and Idaho formations. It possesses a great thickness and overlies the Columbia River basalt and the Owyhee rhyolite. It has a characteristic lithology and a fauna and flora of Pliocene and later age. By the revision, new age relations, stratigraphic positions, and areal distribution are established but no confusion results because at the same time the originally assigned names and ages, which are now established in the literature, may be retained.

INTRODUCTION

The data and conclusions presented in the following pages are results of field work undertaken for the Idaho Bureau of Mines and Geology in executing economic investigations. The writer spent eight weeks of field work on parts of the area in 1920 and the main regional stratigraphic and structural implications were gained at that time. These were amply confirmed by subsequent more detailed work which constituted a week's work in November, 1921, a week's work in 1926, and four weeks in 1927. Finally, the earlier results were enriched and amplified by twelve weeks of detailed work on the

¹ This work was done in co-operation with the Idaho Bureau of Mines and Geology, and the results are published with the permission of the secretary.

map area in 1928. The bulk of the material presented herein has thus been under consideration by the writer for ten years.

ACKNOWLEDGMENTS

The writer acknowledges with appreciation aid from the Idaho Bureau of Mines and Geology which financed the field work for this paper, help from the United States Geological Survey in the determination of fossils, and many suggestions from various members of the Department of Geology, University of Chicago. Courtesies also were extended the writer by various secretaries of the Idaho Bureau of Mines and Geology. Able assistance was given in the field by Messrs. M. Melville Johnson, H. L. McKinley, and Clarence F. Myrene.

HISTORY OF THE PAYETTE AND IDAHO FORMATIONS

In 1870 Meek¹ gave a list of invertebrate fossils collected from Tertiary sediments on Castle Creek, Idaho. These he correlated with other fossils collected from Fossil Hill, Nevada. *Sphaerium*(?) *idahoense* was determined from both localities and was the basis for correlation. On this basis King,² in 1878, when assigning the Truckee group to the Fossil Hill, Nevada, beds also applied that name to the beds on Castle Creek, Idaho. White³ noted, in 1882, that King assigned the Castle Creek group of beds to the Truckee group. He also assigned a Miocene age to the beds.

In 1883 Cope⁴ described fish remains from sediments at a Castle Creek locality and called them the "Idaho group." He assigned to them a Lower and Middle Pliocene age. He also placed Meek's mollusks from Castle Creek and Fossil Hill in this group with a Pliocene age. King, in 1878, referred the Truckee group to the Miocene, but he referred the Idaho beds to the Pliocene.⁵

In 1898 Lindgren⁶ gave the name Payette formation to a large area of lake deposits in this region. These he referred to the Miocene

¹ F. B. Meek, *Acad. Nat. Sci. Phila. Proc. for 1870*, pp. 56-57.

² Clarence King, *U.S. Geol. Expl., Fortieth Par. Rept.*, Vol. I (1878), pp. 412, 440.

³ C. A. White, "The Idaho Formation," *U.S. Nat. Mus. Proc.*, Vol. V (1882), p. 100, Pl. 5, Figs. 17-20.

⁴ E. D. Cope, *Acad. Nat. Sci. Phila. Proc. for 1883*, pp. 153-66.

⁵ *Op. cit.*, p. 440.

⁶ Waldemar Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part III (1898), pp. 625-736.

on the floral evidence determined by Knowlton.¹ Lindgren said, in naming this formation, that,

This formation is probably not the same as Cope's Idaho formation, to which a Pliocene age was assigned.

In a footnote on this page he said:

From the results of more extended surveys during the summer of 1897 it has become evident that the Payette and Idaho formations represent two successive stages of the lake, the often deformed shore line of the former being found at elevations of from 4,200 to 5,000 feet, and those of the latter at a maximum elevation of 3,000 feet. To separate the deposits of the two formations is not always easy.

In 1902 Knowlton² changed his interpretation of the age of the Payette formation from Upper Miocene to Upper Eocene. He said:

In this report the Payette formation was referred to the Upper Miocene, but I was misled by the knowledge then current regarding the position of the Bridge Creek beds, as I have already pointed out, and it is now necessary to change that reference. The flora of the Payette formation undoubtedly finds its greatest affinity with that at Bridge Creek, a fact recognized all along, and, like it, is now referred to the Upper Eocene.

Lindgren,³ in 1904, first recognized areal outcrops of the Idaho formation. He said:

In the vicinity of Nampa the later lake beds and basalt filled the valley to elevations of 2,700 to 2,800 feet, and the sediments contain numerous bones of mammals and of fishes. . . . The age of the scant fauna has been determined as Pliocene by Professor Lucas, and the name Idaho formation has been given to these beds. . . . For practical purposes the Tertiary lake beds form one continuous series, for it is not always possible to separate with certainty the deposits of the Payette formation from those of the Idaho.

Russell⁴ and Washburne,⁵ in his 1909 paper, accepted Lindgren's division of the lake beds and agreed with him that the two are

¹ F. H. Knowlton, "Fossil Plants of the Payette Formation," *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part III (1898), pp. 721-44, Pls. XCIX-CII.

² F. H. Knowlton, "Flora of the John Day Basin," *U.S. Geol. Surv. Bull.* 204, p. 110.

³ Waldemar Lindgren and N. F. Drake, "Descriptions of the Nampa Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio* 103 (1904).

⁴ I. C. Russell, "A Geological Reconnaissance in Southern Oregon," *U.S. Geol. Surv. Fourth Ann. Report* (1884), pp. 431-64; "Geology and Water Resources of the Snake River Plains of Idaho," *U.S. Geol. Surv. Bull.* 199 (1902); "Preliminary Report on Artesian Basins in Southwestern Idaho and Southeastern Oregon," *U.S. Geol. Surv., Water-supply Paper* 78 (1903).

⁵ C. W. Washburne, "Gas and Oil Prospects near Vale, Oregon, and Payette, Idaho," *U.S. Geol. Surv. Bull.* 431 (1909), pp. 26-35.

practically indistinguishable in the field. In 1912 Blackwelder¹ wrote, "The Payette formation, which seems to be safely identified by fossil plants as of late Eocene age."

In 1913, Umpleby² said that Knowlton had determined fossil leaves from beds in Lemhi County, as Miocene. Umpleby correlated these with the Payette formation and believed these beds to be an extension of the Payette which, by inference, he believed to be Miocene.

In 1913, Umpleby³ pointed out that Lindgren and Russell believed that the Hailey and Salmon City lake beds are Payette in age, and inferred later in his text that the Payette may also be Miocene, and that an Eocene age may be incorrect.

In 1917, Merriam⁴ said:

The Idaho formation is not as yet satisfactorily separated from the Payette, Eocene or Miocene and from a Miocene or Pliocene stage which may intervene between the Payette and Idaho. It is, however, quite certain that there exists over a large area of Southwestern Idaho a formation several hundred feet thick which may show evidence of deformation and which contains a fauna of a stage representing either the latest Pliocene or the earliest Pleistocene.

Buwalda,⁵ in his paper published July, 1921, reviewed the history of the two formations briefly, and said:

The investigations of the writer appear to indicate that at least the larger part of the areas regarded as Eocene age are in reality Miocene, or possibly Lower Pliocene, and that the Idaho formation, if Pliocene, was deposited very late in that epoch and may be Pleistocene in age. It is probable, moreover, that the Tertiary strata are divisible into more than two formations. Collections of mammalian fossils made by the writer in Idaho very near the Oregon boundary suggest that the Payette formation is itself divisible into at least two formations of somewhat different age.

¹ Eliot Blackwelder, "The Old Erosion Surface in Idaho," *Jour. Geol.*, Vol. XX (1912), pp. 410-14.

² Joseph B. Umpleby, "Geology and Ore Deposits of Lemhi County, Idaho," *U.S. Geol. Surv. Bull.* 528 (1913).

³ Joseph Umpleby, "The Old Erosion Surface in Idaho," *Jour. Geol.*, Vol. XXI (1913), pp. 224-31.

⁴ John C. Merriam, *Calif. Univ. Dept. Geol. Bull.*, Vol. X (1917), p. 432.

⁵ J. P. Buwalda, "Oil and Gas Possibilities of Eastern Oregon," *Ore. Bur. of Mines and Geol.*, Vol. III, No. 2 (1921).

Chaney,¹ in 1922, discussing the Payette formation, said, "At this time the writer is satisfied to make the reference to the Miocene without further specifications."

In 1923, Buwalda² assigned a Middle or Lower Miocene age to the Payette under the rhyolite, but also said:

The Poison Creek formation immediately overlying the rhyolite is made up of ash, clays, shales and sandstones very similar to the Payette but contains mammalian fossils indicating an age Lower Pliocene or later.

On the same page he said:

The Idaho formation lies in the middle and flatter part of the valley unconformably on the underlying formations. It is generally made up of cream-tinted silt and volcanic ash. Mammalian remains indicate a Pleistocene age.

Gilbert,³ in 1890, also argued for Pleistocene age for the Equus beds and the Equus fauna.

Buwalda,⁴ in July, 1924, said:

In the course of field studies in the Snake River region the writer secured remains of two mammalian faunas from the Payette. One occurs in the lower part of the formation, in beds beneath the interbedded rhyolite, about one mile north of Rockville, shown on the Silver City quadrangle of the U.S. Geological Survey. The second was found in the same section in strata overlying the rhyolite, probably disconformably, near Sands, about 11 miles northeast of Rockville. The beds at both localities dip to the north beneath the nearly horizontal Idaho formation, from which they are easily discriminated by their attitude and lithology.

In speaking of the lower fauna on the same page, he said, "This fauna may represent the middle Miocene, but it is more probably of upper Miocene age, and possibly even lower Pliocene."

In speaking of the Sands fauna, he said, "The age of the fauna is approximately lower Pliocene."

He also said,⁵ "The Payette overlies, probably conformably, the

¹ Ralph Chaney, "Notes on the Flora of the Payette Formation," *Amer. Jour. Sci.*, 5th Series, Vol. IV (1922), pp. 214-22.

² J. P. Buwalda, "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *Ida. Bur. of Mines and Geol., Pamph. 5* (1923).

³ G. K. Gilbert, "Lake Bonneville," *U.S. Geol. Surv. Mono. I* (1890), pp. 393-402.

⁴ J. P. Buwalda, "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *Sci.*, Vol. LX, No. 564, pp. 572-73.

⁵ *Op. cit.*, p. 573.

Columbia River lavas, which in other localities have been determined to be approximately Middle Miocene in age."

In December, 1924,¹ the writer quoted Buwalda's² paper of July, 1923, for the ages of the formations. The writer, at this time, was inclined to substitute the name Poison Creek for the Idaho formation and to consider only one formation to overlie the rhyolite.

In June, 1928,³ the writer said:

The geological column of the Weiser quadrangle of Middle Miocene age has, so far as observed, the Columbia River basalt at its base. This is succeeded by about 600 feet of continental and lake-bed sediments which are tentatively called the Payette formation. Above these sediments lies about 600 feet of lava, also assigned to Columbia River basalt.

Immediately overlying the upper basalt occurs the massive grit or sandstone locally known as the Boise sandstone. This formation, along with a varying thickness of sandy and shaly layers, is assigned to the Poison Creek formation of probable Pliocene age. Above this, and with a slight angular unconformity, lies several hundred feet of almost unconsolidated but distinctly stratified sands and clays, which are tentatively called the Emmett formation and which have their origin in deltas, fans and alluvial flood plains of Pleistocene age.

It can be seen that the Payette was here referred to the series underlying the Columbia River basalt and that the tendency was again to substitute Poison Creek for Idaho as a name for the series overlying the basalt. The name Emmett was first proposed here as a term to include part of what was originally called Idaho. A Middle Miocene age is here assigned to the true Payette and a Pliocene age for the sediments overlying the Columbia River basalt.

In 1929, Bryan,⁴ in writing of the Payette and Idaho formations, accepted Lindgren's original definitions of them, but said, "It is difficult to distinguish between these formations, and the deposits mapped and described in this report as Payette formation may in places include beds belonging to the Idaho formation."

¹ Virgil R. D. Kirkham, "Oil Possibilities and Drilling Activities in South Idaho," *Ida. Eng.*, Vol. II, No. 1 (December, 1924).

² "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *op. cit.*

³ Virgil R. D. Kirkham, "A Brief Preliminary Report on the Possibilities of an Underground Water Supply for the City of Weiser, Idaho," *Ida. Bur. of Mines and Geol. Pamph.* 29 (June, 1928), p. 1.

⁴ Kirk Bryan, "Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon," *U.S. Geol. Surv., Water-supply Paper* 597A (January, 1929).

In summary, the lake beds were called Truckee group by King in 1878; Idaho group by Cope in 1883; Payette and Idaho formations by Lindgren in 1898; Payette, Poison Creek, and Idaho formations by Buwalda in 1923; Payette and Poison Creek formations by Kirkham in 1924; and Payette, Poison Creek, and Emmett formations by him in 1928. The Payette beds have been assigned by various writers to each of the Tertiary periods. The Idaho beds have been assigned to the Miocene, Pliocene, and Pleistocene. Up to the time of this paper all writers, except Bryan, avoided differentiation of the Payette and Idaho, and showed no boundaries on areal maps. Bryan, on his Plate III, showed about a quarter of a square mile of Idaho formation without boundaries. Lindgren¹ in his text vaguely referred the Idaho formation to the region "in the vicinity of Nampa" and to elevations below 2,800 feet.

Lindgren² suggested that the lower part of the Payette was interbedded with the early Neocene basalt. On the same page he said, "North of Marsh the beds are sandy, with subordinate layers of brown clayey tuff. They appear to dip below the Squaw Butte basalt flow on the west and to be underlain by basalt flow on the east."

Lindgren and every other worker up to Buwalda considered the lake beds and terrestrial material overlying the basalt on the north side of the plains, and overlying the rhyolite on the south side, to be chiefly Payette formation covered in places with minor amounts of Idaho formation. Buwalda³ recognized that the Payette is interbedded with the Columbia lavas, and said "Rhyolite flows of 1,000 feet in thickness overlie the Payette for a great distance on the south side of the valley."

This statement apparently consigns the Payette to a position below the rhyolite. In the next paragraph he said, "The Poison Creek formation immediately overlying the rhyolite is made up of ash, clays, shales, and sandstones very similar to the Payette but contains mammalian fossils indicating an age of lower Pliocene or later."

¹ Lindgren, *op. cit.*

² Waldemar Lindgren, "Description of the Boise Quadrangle," *U.S. Geol. Surv. Geol. Atlas Folio 45* (1898).

³ Buwalda, "A Preliminary Reconnaissance of the Gas and Oil Possibilities of South-eastern and South Central Idaho," *op. cit.*, p. 2.

This statement indicates clearly that Buwalda believed the sediments below the rhyolite to be Payette but that the sediments above the rhyolite were not Payette. This is also indicated by the new name of Poison Creek formation assigned to this group. This was the first time that sediments above the rhyolite were excluded from the Payette.

Buwalda,¹ in 1924, apparently reconsidered and decided that the Poison Creek is the top part of the Payette. In speaking of two faunas from the Payette, he said, "One occurs in the lower part of the formation, in beds beneath the interbedded rhyolite. . . . The second was found in the same section in strata overlying the rhyolite, probably disconformably."

Although he assigned a greatly different age value to the two faunas, he was apparently willing to consider them both Payette. On page 573, he said, "The Payette overlies, probably conformably, the Columbia River lavas."

The writer,² in his 1924 paper, accepted Buwalda's 1923 conclusion and confined the Payette to the sediments below the rhyolite and gave Buwalda's name Poison Creek formation to all of the sediments above the rhyolite and to those above the Columbia River basalt on the north. The writer,³ in 1928, reiterated this idea specifically for the Weiser area where it is plainly stated that the Payette represented lake beds underlying 600 feet of Columbia River basalt. At this time, however, the beds above the basalt were not all classed as Poison Creek, and the Emmett formation was suggested for a limited area near Emmett that was not characteristic of the Poison Creek formation.

The idea of unconformability, probably engendered by the conception of age differences, seems to have been held generally by all writers.

Buwalda considered the Idaho formation to be unconformable with Poison Creek. The writer accompanied him on this field work and although he failed to see actual angular unconformable contacts,

¹ "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *op. cit.*

² Kirkham, "Oil Possibilities and Drilling Activities in South Idaho," *op. cit.*

³ Kirkham, "A Brief Preliminary Report on the Possibilities of an Underground Water Supply for the City of Weiser, Idaho," *op. cit.*

he accepted the idea of angular unconformity of the so-called Idaho formation with the Poison Creek formation and carried it up to 1927. The 1928 field season convinced the writer that evidence is lacking for an angular unconformity in lake beds above the Columbia River basalt and rhyolite.

The writer is now prepared to present evidence to support the following ideas. (1) A series of terrestrial deposits and lake beds exists in the Columbia River basalt 600 or more feet below its upper surface. This series presents a characteristic lithology and a flora of Miocene age. (2) A series of terrestrial deposits and lake beds, in places several thousand feet thick, overlies the Columbia River basalt and the Owyhee rhyolite and presents a characteristic lithology and a flora and fauna of Pliocene and later age. According to the original definitions of the Payette formation none of the upper series may be included in it, but the series underlying the basalt and rhyolite can be shown to be true Payette. According to the original definition of the Idaho formation, all of the upper series should be included in it.

If this age relation, stratigraphic position, and areal distribution can be established by this paper, confusion can be dispelled and at the same time the originally assigned names and ages, which are now well established in the literature, may be retained.

PHYSICAL EVIDENCE

For convenience throughout the rest of this discussion, the Tertiary sediments will be defined as follows: *basin beds* will refer to all lake beds and terrestrial sediments overlying the upper flow of the Columbia River basalt or the rhyolite. *Intermontane beds* will refer to all lake beds and terrestrial sediments underlying several hundred feet of Columbia River basalt or rhyolite. These, in no case, occur in the plains area.

STRUCTURAL RELATIONS

The basin beds overlie the Columbia River lava on the north edge of the plains without marked angular unconformity (see Fig. 1, A₅-A₆) but with considerable disconformity caused by erosion of the upper basalt flows before deposition of the basin beds. They also overlie the rhyolite on the south border of the plains without marked

angular unconformity, but with a similar disconformity. The basin beds lie in a structural depression of great size called in this paper the Snake River downwarp and their distribution is confined to the downwarp area (see Figs. 1 *B*, 13). These beds strike generally in a

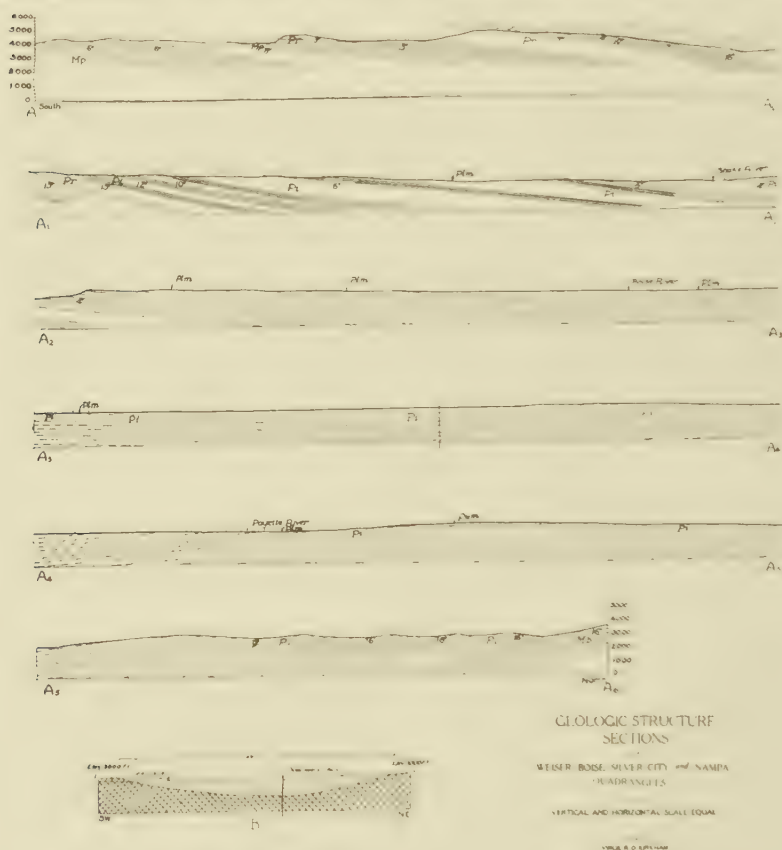


FIG. 1.—*Mp* is the Payette formation, *Pr* is the rhyolite series, *Pl* is the Idaho formation, *Plm* is the Lower Mesa formation, and *Pum* is the Upper Mesa formation. *Mb* is Columbia River basalt.

direction approximately parallel to the downwarp axis and dip at varying degrees toward the center of the depression and approximately at right angles to the downwarp axis. The lower beds cropping out close to the lava at the edges of the downwarp, dip more steeply than those slightly farther out in the valley (see Figs. 2 and

3). Thus a traverse at right angles to the strike of the downwarp takes the observer over the truncated edges of beds dipping pro-



FIG. 2.—Looking southeast along the strike of the Idaho lake beds which dip south-west to the downwarp axis near Alkali Creek on the north side of the downwarp.



FIG. 3.—Idaho lake beds dipping gently to the downwarp axis from the south side. These are characteristic of the upper members.

gressively less as he approaches the axis of the depression. For example, a member near the rhyolite on the south side of the down-

warp actually dips northeast at an angle of 12° . In less than a mile in the direction of dip the angle has insensibly lessened to 11° , and in a distance of another mile the angle of dip has decreased to 10° .



FIG. 4.—Idaho beds in the Weiser quadrangle dipping southwest to the axis of the downwarp.

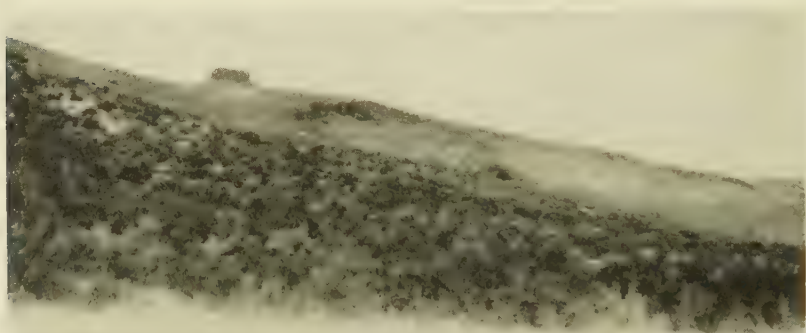


FIG. 5.—Idaho beds in the Nampa quadrangle overlying the rhyolite and dipping toward the downwarp axis to the northeast. Note the irregular surface of the rhyolite projecting through the lake beds.

or less. The highest dips measured in the basin beds on the south side of the downwarp were 16° in a member immediately overlying the rhyolite (Fig. 5 and Fig. 7). About 9 miles closer to the axis of the downwarp the dip has decreased to 4° (Fig. 3). Still nearer the

axis of the downwarp the dips grow less until they approach horizontally 20 miles from the first point. The same phenomenon is observed on the north side of the downwarp axis, except that along the north side the dips are steeper (Fig. 2 and Fig. 4). The beds immediately overlying the basalt dip at angles as high as 29° in places. Eight miles nearer the axis the dip has decreased to 16° or less. At other places on the north side where the dip is 18° at the border it decreases to 7° within 3 miles. In each case there is a progressive range of dips between the two extremes, with a change so insensible that angular unconformities are undetectable. The phenomena, as a whole, are explained by continuous deposition in a progressively sinking area. The beds which were deposited first have been tilted most, and those deposited last have been tilted least, with all gradations existing in between. If one starts at the edge of the downwarp and walks a mile toward the center of the basin he will be standing on sediments several hundred feet stratigraphical-



FIG. 6.—Looking east, beds of the Idaho formation dipping northeast on the south side of the downwarp

ly higher than those from where he started. These obviously are also later in age, and in the course of several miles one passes over several thousand feet of sediments representing a great time interval. Obviously fossils collected from the last deposited beds probably would not be identical with those deposited at the bottom of the series or at horizons in between.

A study of the literature shows that before the reconnaissance by Buwalda and the writer in 1920, this inward dipping relationship was not commonly recognized. The basin beds were universally assumed to be nearly horizontal with the Idaho formation lying in the



FIG. 7.—Looking north at Payette lake beds, on the left, dipping east under Columbia River basalt on the right, near Cobb Siding.

center of the basin and thinly masking the Payette except where erosion had cut through it into the supposed underlying Payette formation. Lindgren,¹ in speaking of the basin beds, which he calls the Payette, said, "Over the larger part of its extent the formation lies nearly horizontal or dips only a few degrees."

In his Boise folio² he duplicates the statement and says, also:

During the time of the maximum extension of the Payette Lake, its surface stood at the present elevation of 4,100 feet. Its deposits, over 1,000 feet thick near the shore, rested against the abrupt slope of Boise Ridge and filled the old canyon of the Boise to the same depth.

It is obvious from this statement that Lindgren believed the beds to have been deposited nearly horizontally and that there had been little or no movement in the region since their deposition. He ap-

¹ *Op. cit.*, p. 632.

² *Op. cit.*, p. 2.

parently thought that the highest remnants of lake beds recorded the highest elevation reached by the lake.

Under the writer's conception the first basin beds were deposited on an approximately level surface of lava which has since been warped¹ so that one of the early level horizons may have later extended from several thousand feet below sea level to several thousand feet above sea level. Persuasive evidence exists for believing that the region now called Boise Ridge was at one time entirely covered by Columbia River basalt and the basin beds, and then uplifted after which most of the lava and basin beds were removed, leaving the present exhumed surface of Boise Ridge dipping at an angle nearly identical with the lake bed and lava remnants at its base.

So far as is shown by the literature all workers but Buwalda and the writer have followed Lindgren in assuming the basin beds to be nearly horizontal. With this idea in mind fossils collected from two nearby localities have been assumed by many workers to represent practically the same horizon. But, as a matter of fact, collections made within a mile of each other if not on the strike of a well-marked member might represent fauna or flora from horizons stratigraphically several hundred feet apart. Thus it can be readily understood how workers, not recognizing the above possibility, have assigned to these basin beds ages ranging from Eocene to Pleistocene.

The intermontane beds on the Boise quadrangle dip at higher angles toward the axis of the downwarp than do the basin beds. This was noted by Lindgren;² he said, "The smaller detached masses in the intermontane valley are still more disturbed, generally dipping at angles up to 50°."

In describing the intermontane beds north of Montour, he said, "The dip is from 3° to 10° W." The writer found a 19° dip to the west in this area. The intermontane beds shown on the map area in the Boise quadrangle are conformable with the overlying Columbia River basalt and dip in a monocline which is the northeast flank of the Snake River downwarp.

The best exposures of the intermontane beds are on the Weiser

¹ Virgil R. D. Kirkham, "Old Erosion Surfaces in Southwestern Idaho," *Jour. Geol.*, Vol. XXXVII (1930), pp. 653-58.

² *Op. cit.*, p. 2.

River. These are confined to Paddock and Linson valleys, and to the valleys of Crane Creek and Weiser River. Here the intermontane beds are exposed only where anticlines in the Columbia



FIG. 8.—Payette beds dipping under the Owyhee rhyolite cap toward the down-warp. The small patch of rhyolite on the right has slumped from the main mass.



FIG. 9.—Payette beds under the upper series of Columbia River basalt in Linson Valley.

River basalt have been eroded through the upper series of flows (see Figs. 9 and 11). On Weiser River erosion has cut through the intermontane beds and into the underlying series of Columbia River lavas (see Figs. 12 *BB*, 13). A similar exposure occurs on an eroded

anticline at Cobb Junction about 13 miles west of Weiser (see Figs. 7, 12 *HH*, 13). Dips on the limbs of this anticline were measured up to 8° . On Weiser River the beds dip as high as 16° on the southwest flank of the fold, and 10° on the northeast flank. Similar dips were measured on the other folds in Weiser quadrangle. In all cases the beds were conformable with the overlying Columbia River basalt and dipped at similar angles.



FIG. 10.—Looking north along the strike of the Idaho beds overlying Columbia River basalt at Black Canyon dam.

In the southern limb of the downwarp the intermontane beds underlie the rhyolite and are exposed in the southwestern part of the map area in Silver City quadrangle. The dip here is flattest farther south and steepens to the northeast, reaching 15° in places. The overlying rhyolite (see Figs. 9, 12 *GG*, 14, 15) has similar dips which steepen notably to the northeast. Thus both the rhyolite and intermontane beds on the southwest limb of the downwarp dip toward the axis.

STRATIGRAPHIC POSITION

That the basin beds overlie the Columbia River basalt and the rhyolite has been generally conceded by all writers. Lindgren showed this relation in several papers. He believed the contact to be disconformable, and said, "On the west the basalts border against

the Payette sandstones and, as far as can be seen, dip below them, forming a very uneven surface, upon which the Payette sandstones were deposited."

He did not say, at any place, anything concerning angular unconformity. Buwalda,¹ in describing the basin beds, said, "The second was found in the same section in strata overlying the rhyolite, probably disconformably."

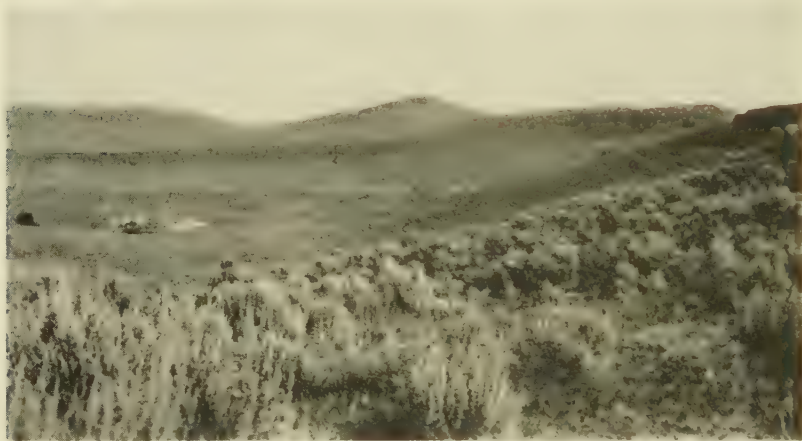


FIG. 11.—Looking south along the strike at basalt beds dipping east from the axis of the anticline in Linson Valley. The patch in the valley is Payette lake beds underlying the basalt.

But on another page he said, "The Payette overlies, probably conformably, the Columbia River lavas."

Stratigraphically the basin beds and the intermontane beds are at all places separated by great thicknesses of lava. On the south side of the plains in the Silver City quadrangle, the basin beds are separated from the intermontane beds by at least 1,850 feet of rhyolite. In the Boise quadrangle only 200 feet of rhyolite separate the two series. At this place, however, the rhyolite exists only as an erosional fragment and undoubtedly at one time possessed a greater thickness.

At Squaw Butte there are 251 flows of Columbia River basalt, dipping at angles ranging from 8° to 40° , between the two series.

¹ "The Age of the Payette Formation and the Old Erosion Surface in Idaho," *op. cit.*, p. 572.

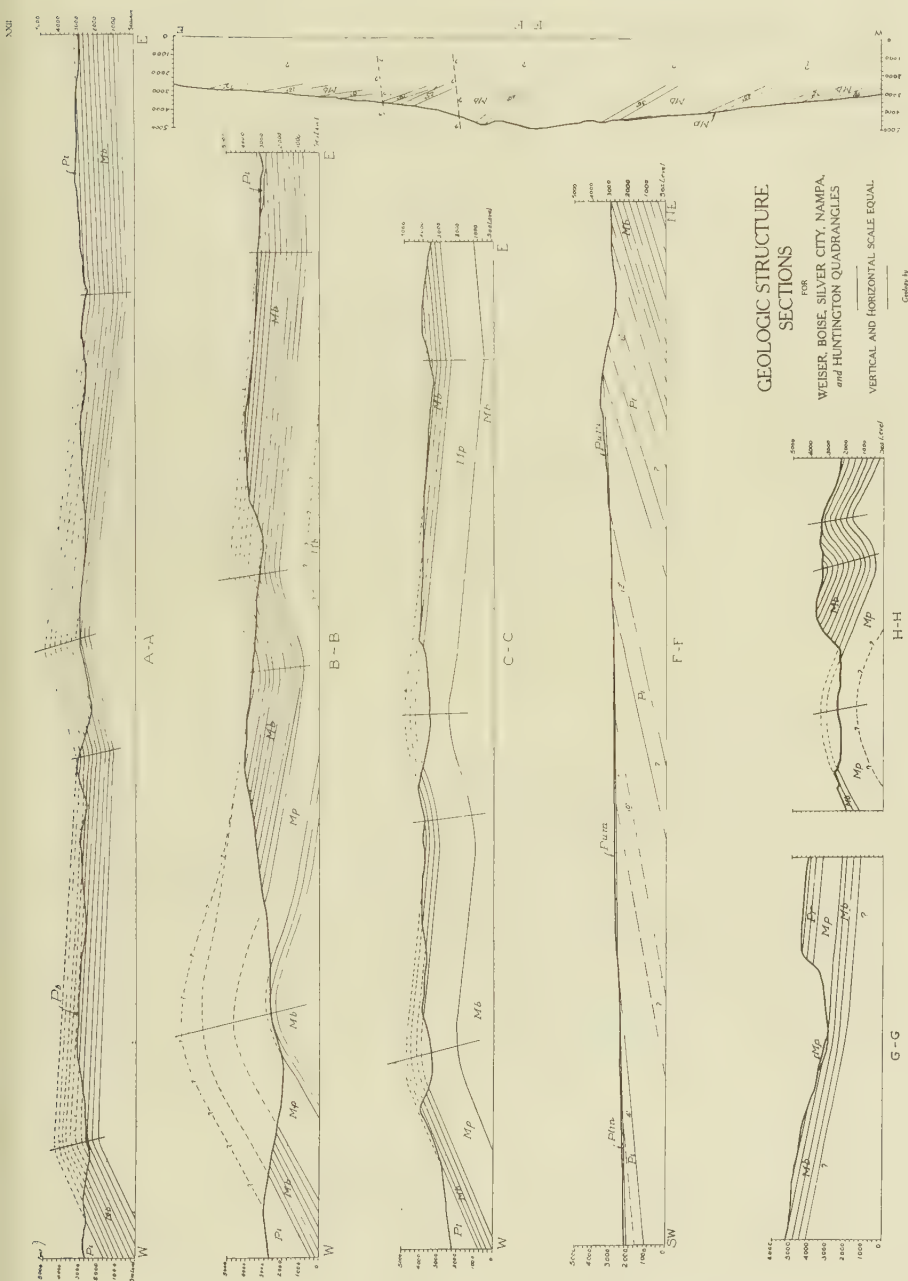


FIG. 12.—*Mb* is Columbia River basalt, *Pi* is Idaho formation, *Pum* is the Upper Mesa formation, *Pim* is the Lower Mesa formation, *Pr* is the rhyolite series, *Mp* is the Payette formation.

This section, carefully calculated, represents a thickness of basalt of more than 17,000 feet if duplication by faulting has not occurred



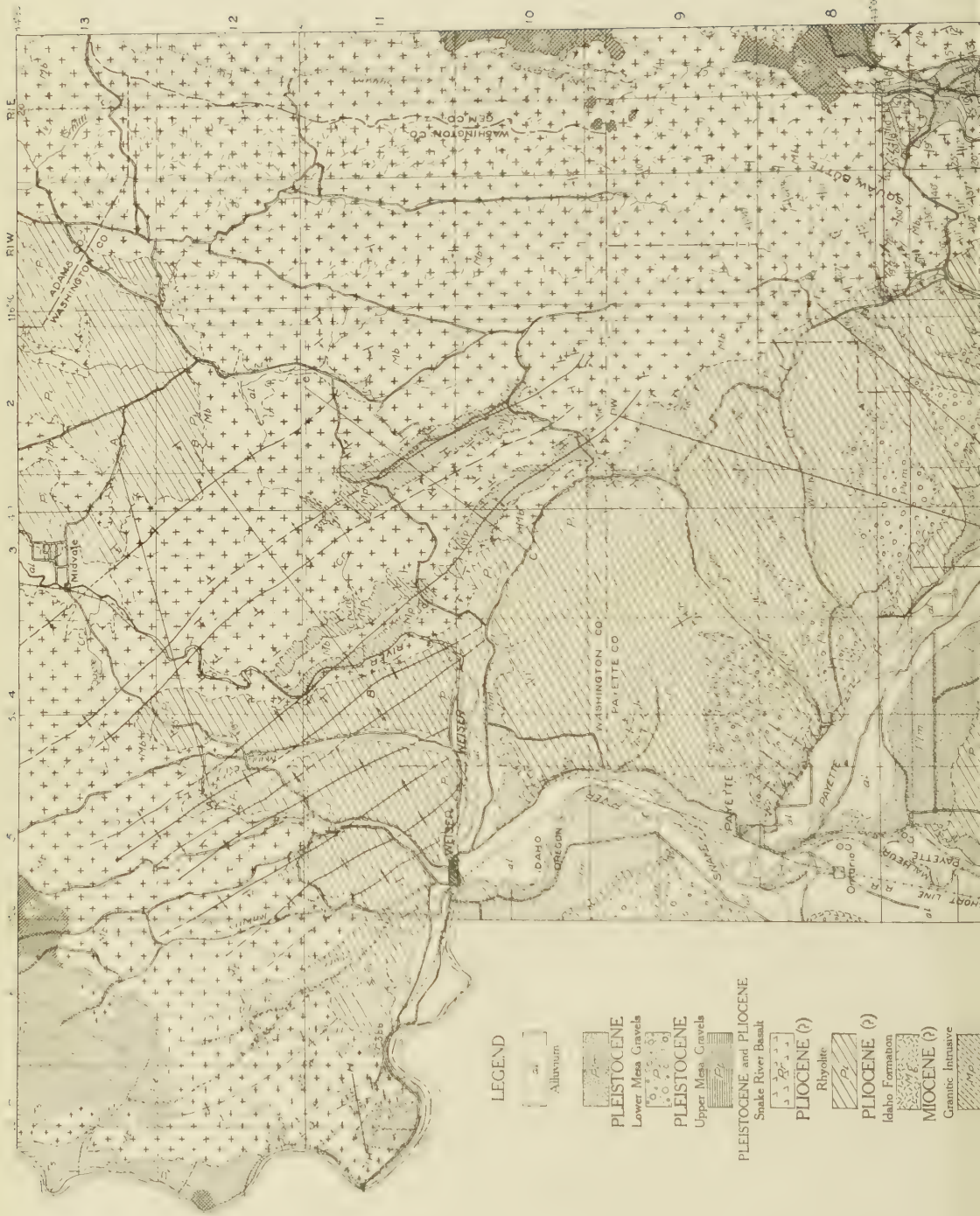
FIG. 14.—Looking northeast at the Payette formation in the Silver City quadrangle, dipping northeast under the Owyhee rhyolite which caps it.



FIG. 15.—Looking north on Little Squaw Creek at the Owyhee rhyolite overlying the Payette lake beds in the middle, and Columbia River basalt underlying the Payette in the foreground.

(see Fig. 12 *EE*). Concerning this area Lindgren¹ said, "The total thickness of the flows appears to amount to many thousand feet. The estimate is qualified by a possibility of duplication by faulting."

¹ "Description of the Boise Quadrangle," *op. cit.*, p. 4.



LEGEND

 Alluvium

 **PLEISTOCENE**
Lower Mesa Gravels

 **PLEISTOCENE**
Upper Mesa Gravels

 **PLEISTOCENE and PIOCENE**
Snake River Basalt

 **PIOCENE (?)**
Rhyolite

 **PIOCENE (?)**
Idaho Formation

 **MIOCENE (?)**
Gneiss Intrusive

 **HOT LINE**

JURASSIC (?)

Granitic Intrusive (dike batholith)

TRIASSIC (?)

Sediments and Volcanics (metamorphosed)

PERMIAN

Volcanics

ANTICLINAL AXIS

SYNCLINAL AXIS

DIP AND STRIKE

LAVA VENTS

Twentieth Diagram

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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K = Area mapped by Kirkham
 L = Area mapped by Livingston
 L + K = Area mapped by Livingston supplemented by Kirkham
 L + K + S = Area mapped by Livingston supplemented by Kirkham and Shreve

GEOLOGIC MAP OF CANYON, GEM, PAYETTE, and parts of ADA, ADAMS, OWYHEE, and WASHINGTON COUNTIES, IDAHO

Areal Geology by Virgil R. D. Kirkham
 Supplemented by comparison with published maps of Wallace, Lindgren
 and others of the U.S. Geol. Survey, and D. C. Livingston
 Structure and Stratigraphy by
 Virgil R. D. Kirkham



Base from U.S. Geol. Survey and Forest Service Maps

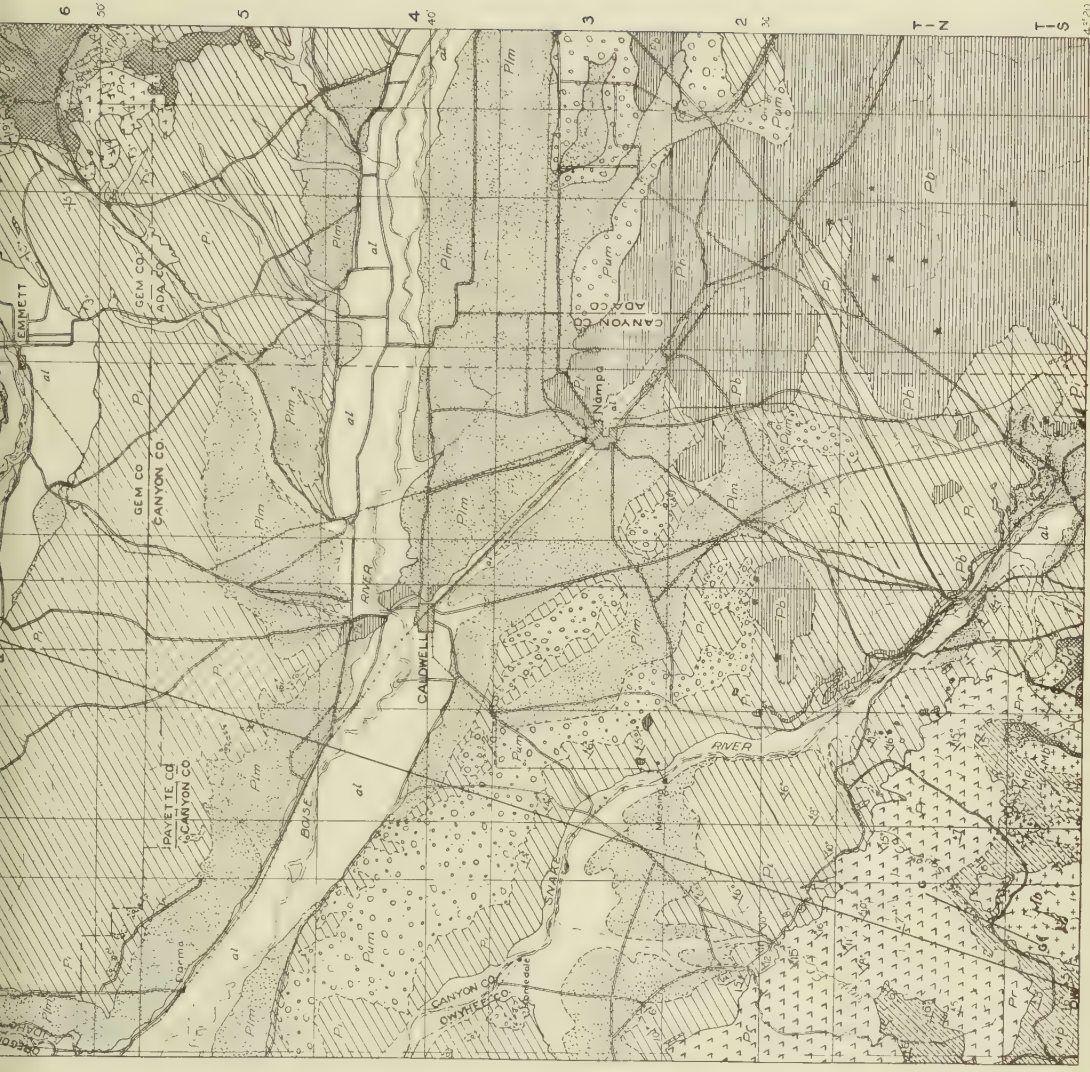


FIG. 13

He showed in his structure section BB the intermontane series dipping under the basalt, and the basin series overlying it. This basalt section was searched for evidence of strike faulting but conclusive evidence was not found. This great thickness extends from Payette River northward to the South Fork of Weiser River for a distance of approximately 35 miles.

At Cobb Siding west of Weiser, a measured thickness of 2,185 feet of Columbia River basalt separate the basin and intermontane beds (see Figs. 7, 12 *HH*).

On Weiser River 680 feet of basalt now separate the two sedimentary series (see Fig. 12 *BB*). There is evidence here that the basalt originally had a greater thickness.

In Crane Creek canyon at least 1,000 feet of basalt overlie the intermontane series and much additional lava has been eroded off the axis of the fold here. At another place south of Weiser River only 445 feet of basalt separate the two sedimentary series, while at another place, still farther south, 720 feet represent the thickness of basalt remaining over the intermontane series.

About 450 feet of basalt overlie the intermontane series on the west side of Paddock Valley and at least 1,000 feet overlie it east of the valley.

South of Payette River the thickness of basalt between the two series is as low as 300 feet at one place.

In summary, the stratigraphic interval between the basin and intermontane sediments is at almost every place very great. The time interval occupied by the outpouring of these great thicknesses of lava cannot be computed but must of course be estimated as of considerable length. An additional time interval of unknown duration must be assigned to the notable disconformity between the lavas and the upper series of sediments. The consideration of this evidence alone would seem to justify the separation of the two sedimentary groups into differently named formations.

LITHOLOGIC EVIDENCE

Lindgren,¹ in his first description of the basin beds, said:

The latter consist chiefly of granitic light-colored sands, locally cemented by hot-springs deposits to hard sandstones (as at Table Mountain near Boise)

¹ "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*

or clayey semiconsolidated sandstones. Heavy masses of conglomerates and gravels begin to appear at Table Mountain, and reach their greatest development opposite the mouth of Boise River, in the high ridge extending in a westerly direction. Purely clayey deposits are rarer, occurring only in convenient sheltered locations near the shore line or in places where volcanic eruptions took place.

Describing them in Boise quadrangle,¹ he said:

They consist predominantly of light-gray arkose, granitic sands, and loose sandstones. The grains are angular or imperfectly rounded, and thus indicate rapid accumulation. . . . The formation appears as light-gray or yellowish, flat-topped, barren sand hills with occasional clayey beds, and with a fairly distinct stratification. The sandstone is ordinarily only loosely cemented, though firmer sandstones occur at Table Rock. . . . Excellent examples of false bedding cutting diagonally across the stratum were noted in the foothills a mile northeast of Boise.

Near Table Rock there are some gravels and conglomerates in the series. At the base lie alternating strata of coarse and fine, loose granitic sand and gravelly beds. Above, the beds are chiefly sandy, alternately loosely and firmly consolidated. North of Table Rock and 200 feet below the summit, lies a firmly consolidated stratum of sandy coarse gravel, the cobbles reaching the diameter of a foot or more. The summit of Table Rock is one continuous stratum of hard sandstone with very distinct lines of stratification and vertical jointing. The lower strata of sandstone are not continuous, but change in places to loosely consolidated material. . . . The area extending from Dry Creek to the north-western boundary is, on the whole, of very uniform character. The strata are light gray, consisting chiefly of loose granitic sandstones, and form flat topped hills cut by many dry gulches. . . . Thin strata of a compact white limestone occur north of Dry Creek, and on the point between the north and south forks of Willow Creek there is a layer of oolitic limestone. . . . A bluff of hard sandstone caps the rhyolite on the north side of South Willow Creek.

In speaking of an 800-foot exposure southeast of Emmett, he said:

Its lower part consists of coarse granitic sand with occasional small pebbles of porphyry. In the upper part the sand is finer; there is a little more material in small streaks, and one 6-inch seam of coaly material was noted. . . .

Similar soft sandstones of granitic origin, dipping gently westward overlie the basalt flow of Squaw Butte, north of the Payette. The strange fact that so little volcanic material is found among these deposits adjoining large volcanic areas has been emphasized in the description of the volcanic rock.

Lindgren,² in speaking of the basin beds which he calls the Payette and Idaho formations, said:

¹ "Description of the Boise Quadrangle," *op. cit.*

² *Ibid.*, p. 2.

Practically, it is not possible to separate these two terranes, and in a large degree the same description applies to both. This is apparent since the material for both came from the same source—the great granite area of central Idaho; and further, a large part of the Idaho formation is simply Payette sediments worked over and redeposited. If clearly defined beach lines once existed they would soon have been obliterated owing to the soft and sandy character of the older, as well as of the younger, deposits.

It is obvious from this statement that Lindgren, like the writer, found the basin beds to be similar in lithologic character and indivisible on strictly lithologic grounds. He said further:

The majority of these beds are unquestionably of lacustrine origin. This is proved by their uniform appearance as well as by the very even stratification and the persistence of certain strata over large areas.

He found gypsiferous beds in the upper sediments and limestones in the lower beds. He recognized relatively small areas of fluvatile and delta deposits. He said:

In general, the strata consist of quartz sands with slight admixture of mica flakes, and thin strata of clays; for the most part they are light gray, buff, or nearly white in color. Strata in which clay is predominant probably make up only one-tenth of the whole amount of the lake bed beds. Occasionally thin interstratified conglomerates and small deposits of pebbles occur. These pebbles consist of granite-porphry and quartz, more rarely of basalt and rhyolite. Toward the north end of the quadrangle¹ the strata are more sandy; angular quartz grains one-tenth of an inch, or less, in diameter are scattered through fine sediments showing imperfect assortment and rapid accumulation; rare and thin lignitic streaks appear in places and seem to be chiefly made up of carbonized grasses, indicating that at various times the lake was shallow and marshy.

In the region including the northern part of the Nampa quadrangle and southern part of the Weiser quadrangle he found, also, “thin intercalated white or gray tuffs which resist weathering so as to form slight breaks in the otherwise smooth steep hill slopes.”

These tuffs he associated with the extrusion of Columbia River basalts in Squaw Creek quadrangle. The writer cannot accept this origin for these tuffs. It has been determined that the Squaw Butte lavas, and all Columbia River lavas in the map area, were extruded before any basin beds were deposited. The “tuff beds” are fine volcanic dust or ash layers which lie several thousand feet stratigraphically above the uppermost Columbia River basalt.

¹ He refers to the Nampa quadrangle.

Russell,¹ describing the basin rocks, said:

The rocks of the Payette formation are mainly sands, clays, and volcanic lapilli, with occasional beds of coarse gravel, especially near the bases of the bordering mountains. The strata have in many instances been consolidated, so as to form sandstone and soft shale, but to a great extent they are still soft, loose sands and slightly compacted sandy clays. . . . I found the ordinary sedimentary beds to be interstratified with layers of white volcanic dust several feet in thickness.

Washburne,² in discussing the basin beds, said:

Below the surface, as is shown by the records of the wells, partly consolidated clay predominates markedly over coarser material, but on the surface of the ground sandy and pebbly beds are most conspicuous. Beds of fine conglomerate are common, the pebbles consisting principally of black chert, quartz, quartzite, and rhyolite. . . . The pebbles are thoroughly water worn and of nearly uniform size in each bed, usually about one-fourth to one-half inch in diameter, although some beds contain pebbles 2 to 3 inches in diameter. The conglomerate is dark colored, generally from iron stain, and in cliffs it resembles flows of basalt, contrasting conspicuously with the light yellow sandy clay and sandstone with which it is interbedded.

The resemblance of this iron-stained conglomeratic grit to basalt is attested to by the fact that an area of this formation, lying chiefly in Secs. 4 and 5, T. 4 N., R. 2 E., is shown on the geologic maps of Boise folio³ as basalt.

Buwalda said in his 1921 paper:⁴

These beds have been considered as lake beds heretofore, but the writer's studies indicate that they are probably in large part river flood plain and waste slope deposits and were laid down only in part in lakes.

Bryan, in describing basin beds, said:

The beds of the Payette formation are largely white or light gray and generally fine grained, but pebble beds and conglomerate also occur. The white sands and shales appear to be largely deposits of river flood plains or are partly consolidated ash of volcanic showers that buried the country and were little worked by streams.

In summary, all writers up to Buwalda appear to believe that practically all of the basin beds show undisputed evidence of lake origin. In general, they believed in the existence of widespread lakes

¹ "Geology and Water Resources of the Snake River Plains of Idaho," *op. cit.*, p. 50.

² *Op. cit.*, p. 27.

³ *Op. cit.*

⁴ "Oil and Gas Possibilities of Eastern Oregon," *op. cit.*, p. 39.

in which these sediments were deposited. These lakes were supposed to have reached to certain levels which they attempted to establish. Bryan as well as Buwalda admitted small lakes but also strongly urged flood plains, deltas, and alluvial fans.

The writer is convinced that conditions varied greatly during the deposition of this great thickness of sediments. Careful detailed work in 1928 has shown that several characteristic strata are very widespread and are found in similar stratigraphic positions on each side of the downwarp. When these sediments were being deposited a rather far-reaching water body existed. At other horizons in the section it is plain that streams constituted the depositing agency. At other places fans and deltas have contributed much of the material, but in no case is there evidence for believing that fluvatile deposition will account for more of the material than lacustrine deposition.

The writer does not conceive of a great Lake Payette and a smaller Lake Idaho as do Lindgren, Russell, Washburne, and others, but visualizes temporary shallow lakes of varying sizes from time to time alternating with intervals of desiccation.

The writer does not disagree with the descriptions by earlier workers of the character and lithology of the lake beds, but he would not generalize so greatly as others. Each method of deposition has a rather characteristic lithology and the section, at one place, may be eroded into a lake-bed horizon, but at another place a fluvatile horizon may be exposed. Here again, former workers have ignored the in-dipping attitude of the truncated strata. In walking a short distance toward the downwarp axis the observer may pass over alternating lacustrine and fluvatile materials.

Many of the "white volcanic ash" beds of earlier writers have been determined to be beds of diatomite which are now commercially worked outside of the area in Oregon.

The sands are chiefly uncemented but in some localities a sand stratum cemented by iron oxide crops out prominently for several miles. Although the outcrop is more obscure where uncemented, such a stratum can be traced from one cemented area to another one. At least three sandstone and two ash beds are valuable horizon markers, and are so extensive as to be valuable aids in locating

stratigraphic position over much of the area occupied by basin beds.

It is believed that a careful microscopic study of ash and diatomite beds will provide the key to the successful working out of the detailed stratigraphy of the basin beds.

If we turn now to the intermontane beds we find that their lithology is unlike that of the basin beds. Lindgren¹ in speaking of intermontane beds said:

The basal part of the formation contains, at Horseshoe Bend, Jerusalem, and other localities along the Payette, small coal seams. In the clay accompanying these coal seams vegetable remains are of frequent occurrence. . . . The plants were obtained near the base of the series, of which about 800 feet of alternating, fairly consolidated shale and sandstone are exposed.

Lindgren,² in another paper, in describing the intermontane beds, said, "The lower part of the series in the intermontane valleys, where the conditions for the formation of clayey beds were most favorable."

At another place he said:

The Payette areas resting in the intermontane valleys are somewhat different from the main deposits in front of the range, and contain clay, tuffs, and coal beds; consequently evidences of plant life are better preserved than in the sandy beds. From strata near the coal was collected the flora upon which rests, in part, the evidence of the early Neocene age of the beds. The beds in the intermontane valleys are also often disturbed and uplifted.

North of Marsh³ the beds are sandy with subordinate layers of brown clayey tuff. They appear to dip below Squaw Butte basalt flows on the west and to be underlain by a basalt flow⁴ on the east.

He said further:

Southwest of Marsh, accumulations of lake deposits lie on the steep granitic slope. The beds which are often greatly disturbed, consist of sandstone, clay, thin coal seams, diatomaceous earth, fine gravels with basaltic pebbles, and brownish tuffs of volcanic glass, and are overlain by basalt. The beds are thus of somewhat earlier age than those on the west which cover the same basalts.

In speaking of another area of intermontane beds, he said:

It consists of a series of well-consolidated sands and clay shales of marked fissility all dipping northwest, west or southwest at angles up to 25°. The top

¹ "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*, p. 633.

² "Description of the Boise Quadrangle," *op. cit.*

³ Now Montour.

⁴ The writer counted 16 underlying flows.

layer is an extremely coarse sandstone difficult to distinguish from the adjoining granite.

Lindgren,¹ in describing intermontane beds in Silver city quadrangle, said:

On the western side of the quadrangle the rocks consist of white shales, sandstones and compact clays. In general, the rocks are finer textured and more consolidated here than elsewhere, and they also extend higher up the mountain-side reaching an elevation of 5,300 feet.

That he recognized the difference between the intermontane beds and the basin beds in this quadrangle is indicated by his description of the latter on page 3:

On the eastern side of the range the conditions are different. Though the beds here are on the whole similar to those on the western side, they are less consolidated and consist of very soft, brilliantly white sandstones, changing in places to compact gypsiferous clay.

Further on he said:

If there had been only one period of deposition in the lake bed series, these deposits would certainly have been formed earlier than the Miocene plant beds of Rockville and Succor Creek.² That this can not be the case is shown by the different petrographic character and decided later fauna of the Snake River beds.³

Lindgren misinterpreted the stratigraphic position of the intermontane lake beds at Rockville and Succor Creek. In his text⁴ and structure sections he shows them to be overlying the rhyolite and basalt; whereas work done by Buwalda and the writer in 1920 showed that their true position was under the rhyolite. Later work by the writer has conclusively proved that all of the area mapped as tuffs on Lindgren's areal map⁵ and structure sections represents typical intermontane beds which underlie the rhyolite and overlie the Columbia River basalt in places (see Figs. 1 *HH*, 8, 12 *GG*, 13, 14, 15) and underlie the basalt in other places.

A study of the intermontane beds by the writer shows that they contain large amounts of ash, shale, and carbonaceous and coal

¹ Waldemar Lindgren and N. F. Drake, "Description of the Silver City Quadrangle," *U.S. Geol. Surv. Atlas Folio 104* (1904).

² These are intermontane beds.

³ These are basin beds.

⁴ "Description of the Silver City Quadrangle," *op. cit.*

⁵ *Ibid.*

seams (see Fig. 7). Some of the latter approach a commercial grade but are relatively valueless because of distance to market.

This same series of tuffs and intermontane beds has been lately described by Bryan¹ under the name "tuffaceous conglomerate." He said:

The oldest rocks within the area are of sedimentary origin and crop out in the Hole in the Ground and in a small area near the north end of the region shown on Plate 3. In both localities the beds lie beneath the Owyhee basalt, but in places in the Hole in the Ground a mass of porphyritic rhyolite intervenes between the two formations. . . . The oldest rocks consist of alternating beds of partly consolidated conglomerate, arkosic sand, and sandy shale of a prevailing buff, light-brown, or green-brown color. Cobbles 6 inches in diameter are common, and a few boulders 1 to 2 feet in diameter were noted. . . . The pebbles and rock grains are all much weathered, and in consequence, determination of the character of the original rocks which supplied the material is correspondingly difficult. The greater part of the material consists of basalt, andesite, and similar igneous rocks, but fragments of quartzitic arkose and single grains of quartz and feldspar are present. The fine-grained beds are water-laid tuffs.

On his Plate X, he showed a yellow tuff member, a tuffaceous conglomerate member and a black shale member to be present in well logs. Bryan apparently recognized an age difference between these beds and the basin beds which he calls the Payette formation, or he would have assigned them also to the Payette formation.

Bryan's mapped outcrop of "tuffaceous conglomerate" lies at a point 10 miles north and 14 miles west of the western border of the map area where the intermontane beds crop out. The writer is confident that Bryan's "tuffaceous conglomerates," because of their lithology and stratigraphic position beneath the rhyolite, belong to the same series exposed in the southwestern portion of the map area.

The intermontane beds are best exposed in Weiser quadrangle on the eroded crests and limbs of anticlines in the overlying Columbia River basalt (see Figs. 11; 12 BB, CC, III; 13). The lithology here is very similar in the various exposures and almost identical with that at Cobb Siding, and with that in Boise and Squaw Creek quadrangles. In all cases the material is well consolidated, the sandstone and ash are resistant, and the shales are well bedded and firm. Thick carbonaceous coaly seams are present at the same horizon

¹ Kirk Bryan, *op. cit.*, Paper 587A (January, 1929).

in each section. At Cobb they have been prospected extensively and approach a commercial grade, as do those in Boise and Silver City quadrangles.

In summary, it can be said that exposures of the intermontane beds in the map area show marked lithologic uniformity. They show a preponderance of ash and shale with relatively thin competent sandstone members. At every exposure occur characteristic ash beds at similar horizons. Carbonaceous seams sufficiently developed to stimulate prospecting for coal are present at essentially the same horizon in the series at each exposure. In some exposures in the Weiser quadrangle isolated basalt flows are interbedded with the sediments, but in no case do they make up more than a small part of the thickness. The intermontane beds are markedly more consolidated than the basin beds.

PALEOBOTANICAL EVIDENCE

So far as can be ascertained no collections were made and determined from the basin beds prior to those made by the writer in the summer of 1928. All of the fossil-bearing localities cited by Lindgren, Knowlton, and Chaney, in establishing the age of the Payette formation, are in intermontane beds which are separated from the basin beds by thick lava series as has been already shown. Inasmuch as all previously determined collections of flora made by Lindgren, Knowlton, and Chaney were from intermontane beds it is clear why their age should not be assigned to the basin beds which have now been proven to lie in a much higher stratigraphic position and above at least one unconformity.

Table I shows the list of species collected by the writer from various localities in the basin beds and determined by Dr. E. W. Berry of The Johns Hopkins University through the courtesy of the United States Geological Survey.

Locality No. 1 is stratigraphically about 1,000 feet above the Columbia River basalt, and is on Alkali Creek in Sec. 17, T. 9 N., R. 2 W., B. M. Leaves are in water-laid brownish diatomaceous clay.

Locality No. 2 is stratigraphically less than 200 feet above the Columbia River basalt and is about 15 miles northeast of Weiser on the North and South Highway, in Sec. 31, T. 13 N., R. 4 W., B. M.

Locality No. 3 is stratigraphically less than 150 feet above the Columbia River basalt and is about 8 miles northwest of Weiser, on Hog Creek, in Sec.

5, T. 11 N., R. 6 W., B. M. The material is lithologically similar to that at Locality No. 2.

Locality No. 4 is stratigraphically less than 500 feet above the Columbia River basalt, and is about 9 miles east of Weiser on the east side of Cove Creek, and $\frac{1}{2}$ mile south of Weiser River. It is in Sec. 3, T. 10 N., R. 4 W., B. M. Ash predominates.

TABLE I

	LOCALITIES				
	1	2	3	4	5
<i>Acer</i> sp. (small leaf)					X
<i>Betula</i> sp.					X
<i>Dryopteris idahoensis</i> Knowlton	X				
<i>Fagopsis longifolia</i> (Lesquereus) Hallick		X			
<i>Ficus washingtonensis</i> Knowlton					X
<i>Laurus similis</i> Knowlton					X
<i>Leuciscus scales</i> (fish)		X			
<i>Librocedrus</i> sp.			X		
<i>Myrica</i> sp.			X		
<i>Odostemon simplex</i> (Newberry) Cockerell*		X			
<i>Phyllites inexpectans</i> Knowlton of Mascall†		X			
<i>Pinus</i> sp. (single needle)			X		
<i>Platanus dissecta</i> Lesquereus	X				
<i>Potamogeton</i> (?) sp.		X			
<i>Quercus cognatus</i> Knowlton					X
<i>Quercus simulata</i> Knowlton			X		
<i>Quercus</i> sp.		X			
<i>Salix florissanti</i> Knowlton and Cockerell					X
<i>Salix inquirenda</i> Knowlton					X
<i>Typha</i> (?) sp.		X			
<i>Ulmus brownelli</i>		X			
<i>Ulmus</i> sp.				X	X

* Includes *Odostemon florissantensis* Cockerell.

† Probably includes *Phyllites payettensis* Knowlton of the Payette, described originally under preoccupied name *Phyllites olivaceus*.

Locality No. 5 is stratigraphically less than 350 feet above the Columbia River basalt and is north of Cove Creek, and about $1\frac{1}{2}$ miles southeast of Locality No. 4. It is in Sec. 12, T. 10 N., R. 4 W., B. M. The leaves are in a massive ledge-making ash or tuff member.

Locality No. 1 is about 30 miles across country from No. 3, and 27 miles from No. 2 which, in turn, is about 12 miles across country from No. 3. Geographically, it can be seen that the localities are rather closely associated. Stratigraphically the range is probably less than 900 feet.

Collections have been made from 18 localities in the intermontane beds. Lindgren,¹ in 1898, gave 4 localities; Knowlton,² in 1898, gave

¹ "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*

² "Fossil Plants of the Payette Formation," *op. cit.*

5 localities, 4 of which were those given by Lindgren; Lindgren,¹ in 1904, gave 2 more localities; Chaney,² in 1922, gave 6 localities, 1 of which is one of the original ones given by Lindgren in 1898. The writer in this paper gives 5 localities, 1 of which is a Chaney locality. The locations of former localities is given in the cited literature. The writer's localities are as follows:

Locality No. 1 is in Sec. 13, T. 11 N., R. 7 W., B. M., about 12 miles west of Weiser north of Snake River in a deep gulch. It underlies 2,200 feet of Columbia River basalt. The leaves were collected from a horizon less than 200 feet below the basalt. This is one of Chaney's localities.

Locality No. 2 is in Linson Valley, Sec. 12, T. 10 N., R. 3 W., about 25 miles by road northeast of Payette. These beds underlie several hundred feet of Columbia River basalt. The leaves are from a horizon about 450 feet below the lava.

Locality No. 3 is also in Linson Valley in Sec. 13, T. 10 N., R. 3 W., about 23 miles northeast of Payette. The beds underlie several hundred feet of Columbia River basalt. The horizon from which the leaves were collected lies about 600 feet below the basalt.

Locality No. 4 is also in Linson Valley, about 1 mile southeast of No. 3. The fossil-bearing horizon is the same as No. 2.

Locality No. 5 is also in Linson Valley, about 2 miles south of No. 4, and also under several hundred feet of Columbia River basalt.

Material was also collected from intermontane beds on Crane Creek, Weiser River, and Jump and Sucker creeks, but nothing has, as yet, been determined. The flora collected from all intermontane localities is listed in Table II.

The Payette flora, as first made known by Lindgren,³ in 1898, showed only 13 species but, as it was described by Knowlton,⁴ in 1898, included 32 species. In Lindgren's Silver City folio were added 12 more of which four were new forms, namely, *Ilex*, *Pteris*, and two *Quercus*. All the others were new to the Payette assemblage.

Chaney⁵, in 1922, added 16 species,⁶ 4 of which were new, bringing the total up to 60 species.

¹ *Op. cit.*

² *Op. cit.*

³ "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *op. cit.*

⁴ "Fossil Plants of the Payette Formation," *op. cit.*

⁵ *Op. cit.*

⁶ Chaney says, *op. cit.*, page 215, that the previously described flora was increased by 17 species but gives a list of species on page 215 in which he lists *Platanus dissecta* previously listed by Lindgren on page 3, *Folio 104*.

TABLE II

	LINDGREN, KNOWLTON							CHANEY	KIRKHAM, BERRY				
	1	2	3	4	5	6	7	6 Localities	1	2	3	4	5
<i>Acacia</i> (pod)						X							
<i>Acer florissanti</i> Kirchner												X	
<i>Acer gigas</i> Chaney								X					
<i>Acer trilobatum productum</i> (?) Heer	X						X						
<i>Acer</i> n. sp.								X					
<i>Acer</i> sp.										X			
<i>Acer</i> fruits						X	X						
<i>Aesculus simulata</i> Chaney								X					
<i>Alnus carpinoides</i> Lesquereux							X						
<i>Betula aequalis</i> (?) Lesquereux	X												
<i>Betula angustifolia</i> Newberry					X								
<i>Betula</i> n. sp.								X					
<i>Betula</i> fruit	X												
<i>Cassia obtusa</i> Knowlton	X												
<i>Castanea castaneaefolia</i> (Unger) Knowlton										X		X	X
<i>Castanea pulchella</i> Knowlton													X
<i>Castanea ungeri</i> Heer							X						
<i>Celastrus lindgreni</i> Knowlton					X								
<i>Celastrus</i> sp							X						
<i>Dryopteris idahoense</i> Knowlton		X											
<i>Equisetum</i> sp.					X								
<i>Ficus underi</i> Lesquereux				X									
<i>Glyptostrobus europaeus</i> Chaney								X					
<i>Ilex</i> n. sp.							X						
<i>Juglans nigella</i> (?) Heer							X						
<i>Juglans hesperia</i> Knowlton		X											
<i>Lampsilis</i> valves									X				X
<i>Laurus princeps</i> Chaney								X					
<i>Leuciscus</i> scales (fish)									X				
<i>Librocedrus</i> sp.									X				
<i>Liquidambar</i> fruit										X			
<i>Myrica lanceolata</i> Knowlton				X									
<i>Myrica</i> (?) <i>idahoense</i> Knowlton	X												
<i>Nyssa</i> stones										X			
<i>Odostemon simplex</i> Chaney								X					
<i>Phyllites flexuosus</i> Knowlton	X												
<i>Phyllites obscurus</i> Knowlton	X												
<i>Pinus knowltoni</i> Chaney								X					
<i>Pinus</i> sp. fruit						X							
<i>Platanus aspera</i> (?) Newberry		X											
<i>Platanus dissecta</i> Lesquereux							X	X			X		X
<i>Platanus</i> sp.							X						
<i>Populus cotremuloides</i> Knowlton	X												
<i>Populus lindgreni</i> Knowlton	X												
<i>Populus occidentalis</i> Knowlton	X												
<i>Potamogeton heterophylloides</i> Berry									X				

TABLE II—Continued

	LINDGREN, KNOWLTON							CHANEY	KIRKHAM, BERRY				
	1	2	3	4	5	6	7	Localities	1	2	3	4	5
<i>Prunus</i> n. sp.....								X					
<i>Pteris</i> n. sp.....							X	X					
<i>Quercus clarensis</i> Chaney.....								X					
<i>Quercus cognatus</i> Knowlton.....									X				
<i>Quercus consimilis</i> Newberry....	X						X	X					
<i>Quercus dayana</i> Chaney.....								X					
<i>Quercus idahoense</i> Knowlton....	X						X		X				
<i>Quercus payettensis</i> Knowlton....					X								
<i>Quercus simplex</i> Knowlton.....		X											
<i>Quercus simulata</i> Knowlton.....	X						X		X		X		
<i>Quercus</i> n. sp.....							X	X					
<i>Quercus</i> n. sp.....							X						
<i>Quercus</i> sp.....		X				X					X		
<i>Rhus payettensis</i> Knowlton....	X												
<i>Salix angusta</i> Brongniart.....		X											
<i>Salix californica</i> Chaney.....								X					
<i>Salix perplexa</i> Chaney.....								X					
<i>Sapindus oregonianus</i> Chaney....								X					
<i>Sequoia affinis</i> Lesquereux.....											X		X
<i>Sequoia angustifolia</i> Lesquereux	X						X						
<i>Sequoia langsforsii</i> (Brongniart)													
Heer.....													X
<i>Sequoia</i> cones.....		X											
<i>Sequoia</i> (?) sp.....									X				
<i>Taxodium</i> sp.....									X				
<i>Trapa americana</i> Knowlton....					X								
<i>Trapa</i> (?) <i>occidentalis</i> Knowlton.					X								
<i>Ulmus californica</i> Chaney.....								X					
<i>Ulmus speciosa</i> Newberry.....					X						X	X	X
<i>Ulmus</i> sp.....						X							

Collections by the writer in 1928 from five localities, one of which was at Cobb Siding, one of Chaney's localities, were identified by Mr. E. W. Berry who discovered no new species but added 11 species new to the Payette assemblage. This brings the total to 71 species for the intermontane beds. The species not common to the Lindgren, Knowlton, and Chaney localities are readily determinable by consulting Table II. Of the 71 species only 13 are common to more than one locality. Chaney¹ says in his paper that 13 species in his collections were common to Knowlton's 32 species of 1898. Unfortunately he did not list his species by localities and thus there are now prob-

¹ *Op. cit.*, p. 215.

ably more than 13 species which are duplicated in the 18 localities represented.

Platanus dissecta is common to several localities of this area and is also a characteristic Miocene fossil of several widespread lake-bed regions. Chaney says, "Clearly it is a strong indication of the Miocene age of the Payette." Other important forms, such as *Ulmus californica* are also urged by Chaney as a valuable indicator of Miocene age. Twenty-three of the 71 species listed in the intermontane beds are common to the Latah flora as listed by Kirkham and Johnson.¹

This large number of duplicates coupled with the similar stratigraphic position² and lithology suggests that the Latah and the intermontane beds of this area are near the same geologic horizon. The southernmost outcrop of the known Latah at Whitebird is only 85 miles from the northernmost intermontane bed of this area. The Latah extends for 200 miles northwest of Whitebird where it crops out at about 50 localities. The Latah formation seems to be of well-established Miocene age, and its similarity to these intermontane beds argues strongly for a similar age for them.

A study of the lists in Table I and Table II shows the basin beds and the intermontane beds have 13 genera, but only 5 species in common. The significant difference, however, between the two lists is the absence of *Sequoia* in the the basin beds of Table I.

That the intermontane flora is of Miocene age is now conceded by all workers. That the basin beds, on the other hand, contain Pliocene flora, is an idea presented here for the first time. Dr. Ralph W. Chaney has considered the evidence and says:³

My studies of the Tertiary floras of the northern Great Basin, including southwestern Idaho, have led me to the conclusion that the presence or absence of *Sequoia* has a significant bearing on the fossil leaves.

I find *Sequoia* in diminishing numbers in the Miocene and absent in the Pliocene in this region. The absence of *Sequoia* in the collections from beds above the basalt in the vicinity of Boise indicates that the age of these beds

¹ Virgil R. D. Kirkham and M. Melville Johnson, "The Latah Formation in Idaho," *Jour. Geol.*, Vol. XXXVII (1929), p. 483.

² The Latah formation underlies several hundred feet of Columbia River basalt, and is in turn underlain by a lower series of Columbia River basalt flows.

³ Written communication.

may be tentatively referred to the Pliocene. A continuation of the studies under way by Mr. Dorf should entirely demonstrate the age of these deposits.

Dr. Erling Dorf, who has studied the evidence, says:¹

The Tertiary lake beds in southwestern Idaho, lying above the Columbia River basalt, contain plant associations which appear to be Pliocene in age.

In summary, all previous collections have been from intermontane beds. The writer presents new evidence in the nature of flora from the basin beds, and collections from new localities in the intermontane beds, which augment that list to 71 species. Chaney and Dorf, paleobotanists most familiar with the Western and Great Basin provinces, consider the basin beds to be notably younger than the intermontane beds and very probably of Pliocene age.

INVERTEBRATE EVIDENCE

Gabb,² in 1866, described invertebrate fossils collected "from a fresh-water deposit on Snake River, Idaho Territory, on the road from Fort Boise to the Owyhee mining country collected by Mr. A. Taylor." The fauna consisted of *Melania taylori*, *Lithosia antiqua*, and a *Sphaerium* from Castle Creek, Idaho.

King,³ in 1878, assigns the beds of this locality to the Pliocene. White,⁴ in 1882, described *Latia dalli* from these deposits. Cope,⁵ in 1883, named these beds the Idaho group and assigned to them an Early or Middle Pliocene age.

Lindgren,⁶ in 1904, reported the finding of *Unio*, *Anodonta*, *Goniabasis*, *Ancylus*, *Corbicula*, *Lithasia antiqua*. Gabb, at a locality 3 miles west of Guffey in the basin beds and 1 mile west of Bernard Ferry, found banks of *Unio* shells. Washburne⁷ reports finding *Carinifex* in that part of Oregon adjoining the Nampa quadrangle.

Dall,⁸ in 1925, mentioned curious fresh-water forms that occur in lake beds in Serbia and Hungary, and said,

¹ Oral communication.

² W. M. Gabb, *Paleontology of California*, Vol. II, Part 2 (1866), Figs. 21-22.

³ *Op. cit.*, p. 412.

⁴ *Op. cit.*

⁵ *Op. cit.*

⁶ "Description of the Silver City Quadrangle," *op. cit.*, p. 3.

⁷ *Op. cit.*

⁸ W. H. Dall, "Discovery of a Balkan Fresh-Water Fauna in the Idaho Formation of Snake River Valley," *U.S. Geol. Surv., Prof. Paper 132G* (1924), p. 109.

They contain a number of genera strikingly different from any now living in the fresh waters of the globe, such as *Valenciennesia*, *Velutinopsis*, *Papyrotheca*, *Orgyoceræas*, and *Boglivia*. There are also a few of the smaller forms like *Caspia* which are now found living or represented by close analogies in the Caspian Sea and Lake Baikal, both of which, it may be noted, are "relict seen."

The chief interest of the present paper¹ lies in the discovery of some of these anomalous fresh-water genera in American lake beds of the Idaho formation, together with one or two curious forms not represented in Europe.

He listed twenty forms from the Idaho formation, of which 2 genera and 6 species are described by Dall as having a remarkable resemblance to marine genera. Several forms are similar or identical to those of the relic seas, Lake Baikal and Caspian Sea. All of these fossils were collected from localities in the basin beds and above the Owyhee rhyolite and Columbia River basalt.

Determinations from collections made by the writer from 5 new localities in the basin beds, in 1928, are as follows:

Loc. I, Sec. 2, T. 8 N., R. 5 W., B. M., about 2 miles east of Payette

Sphaerium sp. a. related to *S. idahoense* Meek but much smaller

Unio sp. near *U. californensis* Lea (recent)

Unio sp. near *U. oregonensis* Lea

Loc. II, Sec. 32, T. 9 N., R. 4 W., B. M., about 5 miles east of Payette

Sphaerium sp. b. n. sp. related to *S. idahoensis* Meek but much smaller. Near to *S. solidulum* Prime (recent), smaller and more elongate than a

Loc. III, Sec. 10, T. 12 N., R. 6 W., B. M., about 10 miles north of Weiser.

The fossils were collected from a horizon less than 150 feet above the Columbia River basalt

Flumincola sp. near *F. nuttalliana* Lea

Sphaerium sp. aff. *S. idahoense* Meek (but thinner shell)

Unio sp.

Loc. IV, Sec. 29, T. 19 S., R. 44 E., Malheur County, Oregon, outside the map area but in basin beds

Flumincola (?) sp.

Sphaerium sp. (may be from the same horizon as Loc. III)

Unio sp.

Loc. V, about 5 miles northeast of Loc. IV

Flumincola sp. near *nuttalliana* Lea

Sphaerium sp. (same as the others)

All of the above forms were identified by Mr. W. C. Mansfield of the United States Geological Survey.

In summary, the invertebrate material collected from the basin

¹ Dall's.

beds, although not strictly definitive, indicates a Pliocene or later age for that series. Several species have a decidedly marine aspect. No invertebrate fossils except *Lampsilis* valves and traces of a large gastropod(?) reported by Dr. E. W. Berry from the writer's localities I and V have ever been reported from the intermontane beds.

VERTEBRATE EVIDENCE

Cope,¹ in 1883, listed vertebrate forms from the basin beds and called these beds the Idaho group which he assigned to a Middle or Lower Pliocene age. Lindgren,² in 1904, listed mammalian forms collected from basin beds in the Nampa quadrangle:

Equus sp., from three localities

Mastodon sp., from two localities

Procamelus, size of *P. major*

Castor n. sp.

Olor, size of *O. paleocynus*

Pappichthys sp.

Cervus sp., smaller and more slender than *C. canadensis*

Lindgren,³ speaking of basin beds, said:

Near Sommercamp ranch, at an elevation of 2,400 feet, bones encrusted with opal were found in sandstone and identified as *Protohippus*, a Miocene or Pliocene genus. In the adjoining Nampa and Bisuka quadrangles mammalian remains, principally *Equus* are frequent in these same beds.

In 1917, Merriam⁴ said:

The Idaho formation is not as yet satisfactorily separated from the Payette, Eocene, or Miocene and from a Miocene or Pliocene stage which may intervene between the Payette and Idaho. It is, however, quite certain that there exists over a large area of southwestern Idaho a formation several hundred feet thick which may show evidence of deformation and which contains a fauna of a stage representing either the latest Pliocene or the earliest Pleistocene.

In 1918, he⁵ said:

As nearly as can be judged the mammalian fauna of the Idaho represents a Pliocene stage later than any other Pliocene fauna of the Pacific Coast and Great Basin regions; with the possible exception of the Tulare Pliocene occurrence on the western border of the San Joaquin Valley.

¹ *Op. cit.*

³ *Ibid.*, p. 3.

² *Op. cit.*, p. 2.

⁴ *Op. cit.*, p. 432.

⁵ John C. Merriam, "Fauna of the Idaho Formation (abstract)," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), p. 162.

Buwalda,¹ in 1921, said "The Idaho formation, if Pliocene, was deposited very late in that epoch and may be Pleistocene in age."

Buwalda,² in 1923, said:

The Poison Creek formation immediately overlying the rhyolite is made up of ash, clays, shales and sandstones very similar to the Payette but contains mammalian fossils indicating an age of Lower Pliocene or later. . . . The Idaho formation lies in the middle and flatter part of the valley unconformably on the underlying formations. . . . Mammalian remains indicate a Pleistocene age.

Buwalda,³ in 1924, in speaking of fauna in basin beds, said:

The second was found in the same section in strata overlying the rhyolite, probably disconformably, near Sands about 11 miles northeast of Rockville. The beds at both localities dip to the north beneath the nearly horizontal Idaho formation from which they are easily discriminated by their attitude and lithology. . . . The age of the fauna is approximately lower Pliocene.

Hipparion teeth near *H. anthonyi* and rodent teeth constitute the most diagnostic material of the Sands fauna.

In discussing carp teeth from the basin beds Buwalda said,⁴ in 1928, "The Idaho formation is either Pliocene or Pleistocene in age."

The writer collected vertebrate material from several localities in the basin beds in 1928, but much of it was valueless or undeterminable in character. Three new localities were established:

Loc. I, Sec. 27, T. 15 S., R. 46 E., in Oregon about 5 miles west of Weiser outside the map area at the "Slides"

Elephas columbi, Pleistocene age

Loc. II, Sec. 17, T. 17 S., R. 46 E., in Oregon, about 9 miles west of Payette, outside the map area and in Jacobsen Gulch

Elephas columbi, Pleistocene age

Camel

Elk or deer

Bison

Loc. III, Sec. 25, T. 12 N., R. 5 W., about 9 miles northeast of Weiser in a gully east of the North and South Highway. Abundant concretions containing fish bones of modern types and

Rhineosites or *Pimelodus*

¹ "Oil and Gas Possibilities of Eastern Oregon," *op. cit.*, p. 38.

² "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *op. cit.*, p. 3.

³ "The Age of the Payette Formation and Old Erosion Surface in Idaho," *op. cit.*, p. 572.

⁴ Written communication.

In speaking of this locality, Dr. J. W. Gidley of the National Museum says¹ these forms are not older than Eocene and may be as late as Pliocene or even Pleistocene. Mr. Gidley also identified the material from the other two localities:

Leusciscus (fish) scales were identified by Dr. E. W. Berry in the writer's paleobotanic locality No. 2, in the basin beds at Sec. 31, T. 13 N., R. 4 W., B. M.

All of the mammalian evidence points to a Pliocene or Pleistocene age for the basin beds.

The intermontane beds, on the other hand, yield very little vertebrate evidence. The only locality was established by Buwalda and the writer in 1920. It is located 1 mile north of Rockville in yellow lake beds west of the road.

Buwalda² said:

The Rockville or lower fauna includes a proboscidean of the *Tetralodon* type, a species of *Hypohippus* resembling other forms in that genus from Middle and Upper Miocene formations of the Great Basin province, *Merycodus* sp., a large camel, a rhinoceros, fish bones, and fresh water shells. Proboscidean remains first occur in North America in the Middle Miocene; they are not abundant until Upper Miocene time. This fauna may represent the Middle Miocene but it is more probably of Upper Miocene age, and possibly even Lower Pliocene.

In 1928 the writer collected fragmentary material from this locality. Gidley³ reported on it as follows, "Mammalian fauna belonging to the Miocene or early Pliocene period, a single fragment of a tooth is recognizable as representing one of the three-toed horses of this general age."

In summary, the vertebrate evidence from the basin beds supports the paleobotanic and invertebrate evidence of their Pliocene and Pleistocene age. Likewise the vertebrate evidence from the intermontane beds is in agreement with the paleobotanic evidence for their Middle or Upper Miocene age.

The Idaho formation by definition is Pliocene and Pleistocene in age, and the Payette formation by definition is Miocene in age. It is now proposed, in the light of foregoing evidence, to give the name

¹ Written communication.

² "The Age of the Payette Formation and Old Erosion Surfaces in Idaho," *op. cit.*, p. 572.

³ Written communication.

"Idaho formation" to all basin beds in this area, and to give the name "Payette formation" to all intermontane beds in this area.

MIOCENE SERIES

PAYETTE FORMATION

Definition.—In the light of evidence presented in the preceding pages, this formation name is applied to the intermontane beds in the map area and contiguous areas in Idaho and Oregon. It consists of a lake bed and terrestrial series several hundred feet thick which generally occurs interbedded with the Columbia River basalt. At some places one or two thin basalt flows are included in the map symbol showing its outcrop. At a few places north of the downwarp it overlies the granite surfaces but at most places it overlies the Columbia River basalt. At some places it is immediately overlain by the Owyhee rhyolite flows, but at most places it underlies the upper series of the Columbia River basalt. At several places erosion has cut through it to expose the underlying formation, usually the lower lava flows of the Columbia River basalt. The beds consist chiefly of well-consolidated ash, carbonaceous or coaly shale and sandstone. The age of the plant fossils is generally conceded by paleobotanists to be Middle or Upper Miocene. The mammalian fossils indicate a Middle or Upper Miocene, and possibly a Lower Pliocene age.

Distribution.—The Payette formation crops out only in intermontane valleys. It is exposed north of the basin at one locality in the Huntington quadrangle, at four localities in the Weiser quadrangle, at four localities in the Boise quadrangle, and at two localities in the Squaw Creek quadrangle. South of the downwarp it occurs at two localities in that part of the Silver City quadrangle lying within the map area. Its thickness averages about 1,000 feet over the entire area, and its lithology is very uniform. Readers wishing details concerning exact location of localities and thicknesses and characteristics for each are referred to the more detailed description following.

Locality descriptions.—The Weiser River locality lies in the southeast part of T. 12 N., R. 4 W., B. M., the eastern part of T. 11 N., R. 4 W., B. M., and in the western part of T. 11 N., R. 3 W., B. M.,

along the valley of Weiser River and the lower part of Crane Creek where it is exposed in an eroded anticline. At this locality a thickness of 1,110 feet is exposed. This includes two interstratified basalt flows with a combined thickness of 285 feet. The total thickness of sediments here is 825 feet; this includes sandstone, ash, and carbonaceous shale. A detailed structure section was surveyed by plane table across this exposure.

The Linson Valley locality lies in Sec. 34, T. 11 N., R. 3 W., B. M., in the eastern part of T. 10 N., R. 3 W., B. M., in the southwestern part of T. 10 N., R. 2 W., and in Secs. 5 and 6 T. 9 N., R. 2 W., B. M., along the headwaters of Little Willow Creek where it is exposed in an eroded anticline (see Figs. 1, 9, 11, 12). The lower members of the formation are not exposed. There are exposed 395 feet of ash and shale exclusive of two interstratified basalt flows totaling 107 feet. A plane table structure section was surveyed across this exposure.

The Paddock Valley locality lies in the eastern part of T. 11 N., R. 3 W., B. M., in the southeastern part of T. 11 N., R. 2 W., B. M., and in the northwestern part of T. 10 N., R. 2 W., B. M., where it is exposed in an eroded anticline on the headwaters of Little Willow Creek. Much of this locality indicated by the map symbol is covered at certain times of the year by a large artificial lake. The amount of erosion here is similar to that in Linson Valley.

The Crane Creek locality lies chiefly in Secs. 35 and 36, T. 12 N., R. 3 W., B. M., and in Secs. 1, 2, and 11, T. 11 N., R. 3 W., B. M., where it is exposed in the deep canyon of Crane Creek across an anticline. The locality shows about 400 feet of ash, shale, and carbonaceous material, much of which is very coaly.

The Cobb locality lies in the west part of T. 11 N., R. 7 W., B. M., and extends southward across the Snake River into Oregon. It is exposed by erosion in an anticline (see Figs. 1, 7, 12). About 410 feet of lake beds are shown here and the base is not exposed. This section includes one interbedded lava flow 40 feet thick. Ash, shale, and coaly carbonaceous seams make up the section here as elsewhere.

The Montour locality lies in Secs. 14, 15, 21, 22, 23, and 29, T. 7 N., R. 1 E., B. M., on the east side of Squaw Creek Valley and north of Payette River. This locality shows a full section of the

formation in a monocline. Its thickness is 1,180 feet, and there are no interstratified lava flows in the ash and shale. The South Montour locality lies in Secs. 3, 4, 35, and 36, T. 7 N., R. 1 E., B. M., southeast of Montour in a monocline. A thickness of 800 feet is indicated here.

The Squaw Creek locality lies in the eastern part of T. 10 N., R. 1 E., along the sides of Squaw Creek Valley. The Squaw Butte locality includes five small outcrops in T. 8 N., R. 1 W., B. M., and two similar outcrops in T. 7 N., R. 1 W., B. M. These are interbedded with the Columbia River basalt and are tentatively assigned to the Payette formation.

The Rockville locality lies in T. 1 N., R. 4 and R. 5 W., B. M., and T. 1 S., Rs. 4 and 5 W., B. M., near the old deserted stage station shown as Rockville, on the Silver City topographic sheet and known locally as the Rocks. It is exposed in a monocline, and at least a thousand feet of this formation can be measured. Here, as elsewhere, ash, shale, and carbonaceous material predominate (see Figs. 1, 2, 3, 8, 12, 14, 15).

The Pearl locality lies in the southeastern part of T. 6 N., R. 1 E., B. M., near the old Pearl mining camp.

Structure.—All exposures are in monoclines where the dipping beds of the formations have been truncated by planation, except in the Weiser and Huntington quadrangles, where the exposures occur in undulations or anticlines on the monocline, the crests of which have been eroded. The monoclines represent either the limbs of the downwarp or the flanks of the great arches which flank the downwarp. The dip in some of these localities exceeds 16° , but in all cases it is consistent with the major structural features (see Figs. 1, 12, 13).

Origin.—During a period of quiescence in the extrusion of the Columbia River lavas, lakes, and swamps, caused probably by damming of old drainage lines by lava flows, became sites for the deposition of sediments. These were at times covered by ash showers which were widespread, and which are represented in all the Payette exposures. Deposition ceased with the recurrence of the lava extrusion.

Extent beyond the map area.—Exposures within the map area are separated by distances of more than 80 miles. South of the map area the Payette formation is known to extend for at least 20 miles. East

of the map area the Payette is known to extend to Idaho City, a distance of nearly 30 miles. Beds containing similar leaf fossils and some of the same species occur near Hailey, on Wet Creek, and near Salmon City, in intermontane valleys where they have been preserved by downfaulting north of the Snake River downwarp.

The Hailey locality is 100 miles east by air line from any Payette exposure in the map area. The Wet Creek area is 65 miles by air line farther east, and the Salmon City area is about 75 miles by air line, north of Wet Creek.

It seems that assigning these localities to the Payette is more hazardous than including the Latah which lies only 85 miles north of a Payette exposure in the map area and includes 23 of the 71 species listed for the Payette formation. Future work may possibly establish that the Latah and Payette formations and the formations exposed at Hailey, Wet Creek, and Salmon City all belong to a relatively long period of quiescence between lava extrusions.

PLIOCENE SERIES

IDAHO FORMATION

Definition.—In the light of evidence presented in preceding pages, this formation name is applied to all basin beds in the map area and in contiguous areas in Idaho and Oregon. It consists of lake beds and terrestrial beds which dip toward the downwarp axis and attain a thickness of several thousand feet in the middle of the basin. It includes all lake beds overlying the Columbia River basalt and Owyhee rhyolite but excludes the Pleistocene Upper Mesa and Lower Mesa formations and alluvium. Interbedded with the upper members is the Snake River basalt. The basal beds and upper beds are preponderantly sandy; but by far the greater thickness of the formation consists of light-colored shales. A few beds of volcanic ash and diatomite are conspicuous in the series. The basal sandstones are in places well cemented and resistant, but on the whole, the formation is poorly consolidated. Most of the formation is well stratified. The plant fossils, according to eminent paleobotanists, point to a Pliocene age. Invertebrate and vertebrate fossils indicate a Pliocene and Pleistocene age.

Distribution.—This formation occurs chiefly in the basin formed

by the slopes of basalt and rhyolite on the north side of the downwarp and the rhyolite on the south side of the downwarp in the map area. It underlies approximately the southwest half of the Weiser quadrangle, practically all of the Nampa quadrangle, the northeast half of that part of the Silver City quadrangle included in the area, about two-thirds of that part of the Boise quadrangle included in the map area, and probably all of that part of Bisuka quadrangle included in the map area, and the extreme southeastern part of the Huntington area. At places it is superficially masked by thin flows of Snake River basalt, by the gravels and silts of the Upper Mesa and Lower Mesa formations, and by alluvium.

Another area of the Idaho formation lies in the northeastern corner of the Weiser quadrangle and the northwestern corner of the Squaw Creek quadrangle. This exposure is separated from the main basin exposure by several miles of Columbia River basalt. Field relations indicate plainly, however, that the two exposures were once joined and that subsequent erosion on the anticlinorium between them has removed a strip of the Idaho formation from 6 to 15 miles wide. Structure sections, Figure 12 *AA*, *BB*, indicate the present relations of the two exposures. The northern exposure lies chiefly on the east flank of a wide and gentle syncline and extends for an unknown distance north of the area.

Thickness.—Many plane table sections were made across the strike of these dipping lake beds, with the following results:

The Little Squaw Creek section crossed 7,275 feet of beds in a horizontal distance of 59,000 feet. This was the greatest thickness measured on the south side of the downwarp. A section west of Jump Creek measured a thickness of 5,600 feet in 51,000 feet of horizontal distance. The Jump Creek section showed a thickness of 5,700 feet in 54,500 feet. The Poison Creek section showed 2,600 feet of beds in a distance of 11,000 feet (see Figs. 4 and 5). The Sommercamp section showed 3,400 feet of beds in a distance of 14,000 feet. All of these sections started at the rhyolite and were surveyed along the dip towards the axis of the downwarp. Each one was extended as far as outcrops were measureable. Nearly all the dips were obtained by the plane table stadia method, and thicknesses were calculated with the use of logarithms.

On the north side of the downwarp the sections were longer and the thicknesses arrived at were greater than those south of the axis. The Haarman section (see Fig. 1), starting at the head of Alkali Creek, extended 83,725 feet or 15.6 miles, and crossed 10,800 feet of beds. A section starting at the basalt and ex-

tending down Little Willow Creek was 68,000 feet long. The calculated thickness of the beds crossed gave the maximum figure measured in the map area of 18,633 feet. These thicknesses were obtained by the planetable stadia method also.

Whether or not these immense thicknesses are correct is impossible to say. It is obvious, however, that the thicknesses assigned by Lindgren¹ and other earlier workers were far from accurate, and were based on the erroneous idea that the beds were deposited in a previously formed great basin, and now lie approximately horizontally. This relationship is shown by Lindgren² on structure sections AA and BB of the Silver City folio.

That the beds extend far below sea level and that they have been deposited in a subsiding area is attested by Washburne's³ statement wherein he said:

The minimum thickness of the Payette and Idaho formations at Ontario, Oregon, is 4,000 feet, the depth of the Ontario gas well, to which should be added about 200 feet of higher strata exposed in the bluffs northwest of the well. The minimum thickness of these formations is therefore about 4,200 feet; the true thickness may be much greater. This figure places the bottom of the Payette formation below sea level under much of the Snake River Valley. At the bottom of the Ontario well the Payette formation is 1,839 feet below sea level as determined by comparing the depth of the well with a near-by United States Geological Survey bench mark.

The "Payette formation" mentioned by Washburne is included in the Idaho formation as here defined. The Ontario well lies within the map area across the Snake River from Payette, and toward the axis of the downwarp which lies several miles to the south. Wells at Payette 1,800 feet deep are still in the Idaho formation and a well at Weiser 1,500 feet deep was still in Idaho sediments, although only 4 miles from the contact where the basalt dips under the lake beds. The Haarman well on Alkali Creek is reported to be 1,875 feet deep. It is still in the Idaho formation although it is less than 2 miles distant from the contact where the basalt dips under the lake beds.

Wells as deep as 1,700 feet, and still in Idaho formation, are located south of Snake River within 2 miles of the contact of the rhyolite where it dips under the lake beds. The well data offer persuasive

¹ "Description of the Boise Quadrangle," *op. cit.*

² "Description of the Silver City Quadrangle," *op. cit.*

³ *Op. cit.*, p. 29.

argument for accepting the greater figures arrived at by planetable traverses and calculation.

Structure.—The Idaho formation lies in two synclinal depressions. The greater one, extending transversely across the map area, is described in this paper as the Snake River downwarp. The minor one is the Midvale syncline in the northeast part of the Weiser sheet.

In the downwarp the Idaho beds dip inward to the axis from the lavas which flank the Snake River Valley (see Figs. 1, 12 *FF*, 13). The dips of the upper members are progressively less toward the axis of the downwarp where the beds become practically horizontal. The steepest dip south of the axis was nearest the rhyolite, and measured 16° . Dips as low as 4° were measured north of Snake River in Nampa quadrangle. The steepest dip north of the axis was nearest the basalt and measured 29° . Dips as low as 3° were measured near Payette, about 15 miles from the basalt contact.

In Weiser quadrangle and the Huntington area the Idaho formation is folded into several closely-spaced, practically parallel, plunging asymmetric folds which affect equally the underlying Columbia River basalt and the interbedded Payette. An examination of the areal map of Weiser quadrangle (see Fig. 13) shows the axes of these structures and the relations of the Idaho formation to the structure. Gentle flexures, possibly due to differential compaction rather than tangential pressure, are obscurely indicated at a few points in the Weiser quadrangle and in the region in Oregon contiguous to the Nampa quadrangle.

The practically unconsolidated sediments lack horizon markers. In all cases where the planetable was used, the reversals of the regional dip toward the downwarp axis were less than 100 feet per mile.

In the Midvale syncline the Idaho formation lies on the eastern flank and dips southwest to the axis at angles of less than 4° .

Origin.—The basal members of the formation were deposited on the flat-lying Columbia River basalt. Soon thereafter subsidence began and in the basin which resulted, deposition was continued. Subsidence also continued and is known to have lasted until after the deposition of the late Pleistocene Lower Mesa formation and may actually be in progress at the present time. The deposition was

chiefly in ephemeral lakes, some of which were relatively widespread, while others were local in character. Intervals of desiccation were marked by flood-plain deposits. Alluvial fans and deltaic deposits were rare but are indicated at a few places. Widespread strata of volcanic ash make up a small part of the thickness.

Extent beyond the map area.—The formation covers a large part of the map area and extends into Oregon for an unknown distance. That it underlies great areas of the downwarp to the east in Idaho is revealed by the deep canyon of the Snake River which has cut through the overlying Snake River basalt and into the Idaho formation for several hundred feet. In Bisuka quadrangle the outcrop becomes narrower and the lateral extent is unknown. These beds are well exposed at Castle Creek, Oreana, Grandview, Glenns Ferry, Hammett, Hagerman, and Melon Valley where the Snake River basalt has been removed by erosion. At Melon Valley, 115 miles by air line from the edge of the map area, where they overlie the rhyolite they gradually pinch out until, at a point a few miles east of Buhl, they are no longer present and the thick flows of Snake River basalt immediately overlie the rhyolite. This relationship is maintained until the rhyolite is no longer visible where the Snake River has not completely cut through the overlying Snake River basalt.

That the formation is more extensive where the downwarping was stronger is a logical inference and the greatest thicknesses and greatest width are probably represented within the map area or farther west in Oregon. The portions of the formation lying in the Midvale syncline extend to an unknown distance northward from the map area.

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VIRGIL R. D. KIRKHAM

SNAKE RIVER DOWNWARP¹

VIRGIL R. D. KIRKHAM

Saginaw, Michigan

ABSTRACT

The history of the idea of subsidence and warping and the development of the idea of geosynclines and downwarps is reviewed, and a suggestion as to classification and definition of subsiding areas is made. Next is presented a review of the widely differing concepts held by many workers concerning the origin of the great arc-shaped depression called the Snake River plain which sweeps across the entire width of Idaho. The writer has accumulated evidence over a period of years which indicates clearly that the depression is a downwarp formed by gentle and very gradual subsidence. This great structure attains especial significance because it does not parallel the grain of the continent or the Rocky Mountain system, but, to the contrary, crosses the latter almost normal to its axis.

INTRODUCTION

The data and conclusions presented in the following pages are results of field work undertaken for the Idaho Bureau of Mines and Geology in executing economic investigations. The writer spent eight weeks of field work on parts of the area in 1920 and the main regional, stratigraphic, and structural implications were gained at that time. These were amply confirmed by subsequent more detailed work which constituted a week's work in November, 1921, a week's work in 1926, and four weeks in 1927. Finally, the earlier results were enriched and amplified by twelve weeks of detailed work on the map area in 1928. The bulk of the material presented herein has thus been under consideration by the writer for ten years.

ACKNOWLEDGMENTS

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¹ This work was done in co-operation with the Idaho Bureau of Mines and Geology, and the results are published with the permission of the secretary.

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THE SNAKE RIVER DOWNWARP

This great structural depression extends in a broad crescent across southern Idaho from Yellowstone National Park to the map area of this report, which it crosses, and extends thence into Oregon for a distance of at least 25 miles (See Fig. 1). The name "Snake River Downwarp" was originally assigned to this depression by the writer¹ in January, 1927. Inasmuch as the origin of this great structural depression has been a matter of controversy for several years, a brief review of the ideas commonly held concerning downwarping are presented in the following pages, before presenting the evidence for considering this particular depression as a typical downwarp.

HISTORY OF THE "DOWNWARP" IDEA²

Strabo (born in 65 B.C.) appears to have first offered the idea that the lands have sunk and risen, assigning to vulcanism a large rôle in these movements. Celsius, in 1743, decided that areas in Scandinavia were subsiding. Although the idea was strongly opposed by many, Linnaeus supported him. When Leopold von Buch entered the lists, in 1802-07, supporting the idea by strong evidence, it became an orthodox conception. Von Buch apparently deserves the credit for establishing the idea of secular upheaval and subsidence. Bruslak, in 1803, argued that the Bay of Naples had subsided, and Prevost advanced evidence for crustal subsidences. Berzelius, in 1835, argued for subsidence as a common phenomenon, and Darwin, in 1839, brought forth subsidence to explain the coral islands of the Pacific. James D. Dana, in 1849, argued for elevation at the poles and subsidence at the equator.

Most of these earlier ideas of subsidence concerned areas chiefly submarine, vast in extent, and with indefinite boundaries. James

¹ Virgil R. D. Kirkham, "A Geologic Reconnaissance of Clark and Jefferson and Parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho," *Ida. Bur. of Mines and Geol. Pamph.* 19, (January, 1927), p. 24.

² Thanks are due to Dr. George Otis Smith, former director of the U.S. Geol. Surv. for suggestions concerning sources of information on this subject.

Hall, in 1857,¹ when discussing the origin of mountains, suggested a slightly different conception of subsiding areas, by saying, "Gradual accumulation of sedimentary masses in areas of subsidence must, on account of the altered equilibrium, give rise to folding and fracturing of the crust and consequently to mountain chains."

On the basis of this concept he outlined areas of subsidence whose boundaries and orientation were essentially similar to mountain chains. Babbage and Herschel had, however, in 1837, noted that areas of subsidence and deposition later became the sites of uplift.

Dana disagreed with Hall's concept of the origin of mountains but accepted his ideas on subsidence and consequent deposition. To the great trough-like hollows of subsidence and deposition he gave the name "geosynclinal." He advanced the idea that mountain systems arose from sediments accumulated in "geo-synclinals" and said, "As subsidence continues, the deeper strata are weakened by heat and pressure and readily tear assunder."

Dana, in 1863, defined "geoclinal" as follows²: "wider depressions lying between distant ranges of elevations were produced through a gentle bending of the earth's crust and these great valleys or depressions (like the Mississippi and Connecticut valleys) may be called 'geoclinal.'"

This represents his preliminary groping for a name to assign to certain types of subsiding, or warped, areas. In 1873, Dana³ established the name "geosynclinal" for these downwarped areas. He said,⁴ "The making of the Allegheny Range was carried forward at first through a long continued subsidence—a geosynclinal⁵ (not a true synclinal).

That he considered it the same depression to which he had assigned the name "geoclinal," in 1863, is indicated by his calling the "Triassco-Jurassic region in the Connecticut Valley" a geosynclinal.

¹ An address before the American Association for the Advancement of Science.

² James D. Dana, *Manual of Geology*, 1st. ed. (1863), p. 722.

³ James D. Dana, "On Some Results of the Earth's Contraction from Cooling, Including a Discussion of the Origin of Mountains and the Nature of the Earth's Interior," *Amer. Jour. Sci.*, 3d Series, Vol. V (1873), 423-43.

⁴ *Ibid.*, p. 430.

⁵ From the Greek—*earth* and *synclinal*, it being a bend in the earth's crust.

He also named the Green Mountain region as a one-time geosynclinal. He attributed the structure to "lateral thrust."

In 1895,¹ Dana altered the term to "geosyncline" and defined it.

Ideas on geosynclines have gradually advanced through the succeeding years and the existence of such features has been generally accepted. Grabau,² in 1921, listed several geosynclines for each continent, and Schuchert,³ in 1923, in his exhaustive paper on the subject, listed a large number for North America and argued for two types of geosynclines: simple and complicated, continental and mediterranean ("between continents"). In speaking of the continental type, he said,⁴ "In North America the geosynclines all lie on the inner or continental side of the borderlands."

He also stated,⁵ "Geosynclines, in the American sense, on the other hand, are long and narrow shallow-water *inland seas* lying wholly upon a continent."

European geologists consider the geosynclines as elongate oceans that are hemmed in by continents and typical "mediterraneans." Suess, Haug, and Ruedemann showed in their maps that some continental types link up with mediterranean types.

Hall's original conception confined the geosynclines to continents, but Dana,⁶ in 1895, gave them a very elastic use. He said,

That there were profound geosynclines over the oceanic basin during the later Tertiary and Quaternary is put beyond question. . . . The Coral Island subsidence, announced by Darwin in 1839, recognized such geosynclines.

In the same text⁷ he made two other applicable statements:

Rocky Mountain geosynclines—local geosynclines, or subsidences, commenced over the summit regions of the mountains. The areas of the fresh-water lakes, referred to above, were the sinking areas; and the sinking went forward with concurrent deposition of beds, until the troughs contained strata of Eocene Tertiary 8,000 to 10,000 feet in thickness. . . . After these Eocene basins ceased to subside, more eastern Miocene and Pliocene geosynclines formed.

¹ James D. Dana, "Manual of Geology, 4th ed. (1895), pp. 380, 385.

² A. W. Grabau, *Text Book of Geology* (1921).

³ Charles Schuchert, "Sites and Nature of the North American Geosynclines," *Bull. Geol. Soc. of Am.*, Vol. XXXIV (June 30, 1923), pp. 151-230.

⁴ *Ibid.*, p. 170.

⁶ *Manual of Geology* (1895) p. 937.

⁵ *Ibid.*, p. 195.

⁷ *Ibid.*, p. 365.

And,

The basin¹ of Lake Superior probably corresponds to a geosyncline as suggested by T. C. Chamberlin.

R. T. Chamberlin² believes that the word "geosyncline" should be chiefly applied to continental structures rather than oceanic or mediterranean, but that fore deeps are genetically similar. Many authorities from Dana down to R. T. Chamberlin, G. R. Mansfield, and Charles Schuchert, of the present time, assign the origin of these structures to lateral pressure. This is the most commonly accepted idea—excluding isostasists who explain all secular upheaval and subsidence by the well-known principles claimed for isostasy.

C. K. Leith³ defined a geosyncline as follows, "A geosyncline is a gentle downwarping."

The use of the term "downwarp" and its relation to "geosyncline" should next be considered.

Bailey Willis,⁴ in his book entitled *Geologic Structures*, said:

Warped surfaces are usually broad and of moderate slopes. Thus, Hudson Bay, the Mississippian embayment, and the valley of California are typical broad downwarps. . . .

Downwarps of past ages are usually represented by the strata that accumulated in them. The Paleozoic trough of the Appalachian Province, the Cretaceous trough of the Rocky Mountain region, the Mesozoic and early Tertiary trough that reached from the Alps to the Himalayas, were all great downwarps. Their bottoms subsided many thousands of feet and the depressions were filled with strata of corresponding thickness, . . . great downwarps of this kind are called *geosynclines*. . . .

Smaller local upwarps and downwarps are of very general occurrence. The upwarps are recognized by rejuvenation of streams and other evidences of accelerated erosion, whereas the downwarps are basins in which sediments accumulate. . . .

Since the strata are usually laid down in basins that are continually deepening, the bottom layers of a deposit must themselves have subsided and been warped. They will have been tilted or have become basin-shaped or trough-shaped, although the uppermost strata may be nearly flat. The strata of any series are therefore not strictly parallel. . . .

The broad type that is produced during the accumulation of sediments or as

¹ *Ibid.*, p. 106.

² Oral communication.

³ *Structural Geology* (1923), p. 234.

⁴ Willis, *Geologic Structures* (1929), p. 17.

a result of regional warping is due to vertical movements, to subsidences, or to uplifts. . . . It is better to call the effects of warping *flexures* and to restrict the terms *folding* and *folds* to mechanical disturbances caused by compression.

In the first edition of the same book,¹ Willis said,

The term folding is broader than that of warping, which is a deflection due to vertical forces, and fold is more comprehensive than upwarp or downwarp.

Willis² in the 1929 edition, said:

Subsiding areas are the gathering places of sediments, both continental and marine, and the earlier deposits, in course of subsidence and in consequence of subsidence, become deeply buried under the later ones. It is demonstrable that the earlier beds were practically flat when deposited, that the thicknesses of the overlying strata vary greatly over the area of deposition, and that the upper surface was also practically flat during and at the close of the process of accumulation. There is, therefore, no escape from the conclusion that the older formations became flexed or warped during the progress of subsidence and in consequence of the vertical attraction of gravity. The structure thus developed is, by definition, an incompetent syncline. It is already well recognized as the "geosyncline" of Dana. It is not limited in occurrence to continental, marginal, or marine areas, and may be represented by the geosyncline of the Alps, by that of the Appalachians, by the basins of the Rocky Mountains, by the Valley of California, or by the Caribbean deep.

The use of the word "warping" in a technical sense seems to have been established by W. M. Davis³ in 1883, when he made free use of it in several papers. Davis, in 1898, so far as is known, was also the first to define "warping" or "warps" and to use these words as technical nouns or names for a definite type of structural feature. In his *Eighteenth Annual Report of the United States Geological Survey*, he defined warping thus:⁴

Deformations of this class are not called "folds" because the dips are, as a rule, of moderate amount, and still more because it is not desired to imply that lateral compression, acting to produce folds after the manner ordinarily attributed to such a force, has had anything to do with the disturbance of the region.

On the next page he wrote an entire section on warps.⁵

Davis thus presented here a fundamental distinction between warping and folding, supported thirty-one years later by Willis, as

¹ *Ibid.*, (1923), p. 140.

² *Ibid.* (1929), p. 258.

³ *Science*, Vol. I (1883), pp. 304-5, 325-27, 356-57, 570.

⁴ *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part II, p. 84.

⁵ *Ibid.*, p. 85.

quoted above. Davis thought the Connecticut Valley to be a "warp" and spoke of the "down-bending of the Triassic trough."¹ Dana, it will be remembered, mentioned this as one of his type geosynclines, as quoted above. Although Davis did not use the work "downwarping" or "downwarp," at this date, he spoke of "flat warping" and "down-bending" in describing what is now commonly called downwarping.

Daly,² in 1905, is believed to have been the first to use the word "downwarp" as a technical name for a type of structural feature. Washburne³ called the Snake River depression "an almost imperceptible broad downwarp or syncline."

In 1918 Barrell,⁴ said:

The recognition of *warping* as a major factor in the large structure of mountain systems, and the expression of that factor in the terms "geosyncline" and "geanticline" forms a notable advance in geologic thought. . . . Since they are needed terms for the larger mountain structure and do not require a determination of the previous limits of upwarp and downwarp.

Buwalda,⁵ in 1923, said, in referring to the map area:

This region is flanked on either side by rugged mountain ranges attaining an elevation of 9,000 feet and is believed to have been caused by a huge downwarping of the crescent-shaped area for a vertical distance of several hundred feet.

The writer,⁶ in 1924, describing the map area, spoke of a "huge downwarping for a distance of several thousand feet," and Piper,⁷ in 1924, said, "Downwarping and erosion of the series progressed into early Pleistocene time."

¹ *Ibid.*, p. 83.

² Reginald A. Daly, "The Accordance of Summit Levels among Alpine Mountains; The Fact and Its Significance," *Jour. Geol.* Vol. XIII (1905), pp. 105-25.

³ C. W. Washburne, "Gas and Oil Prospects near Vale, Oregon and Payette, Idaho," *U.S. Geol. Surv. Bull.* 431 (1909), pp. 26-35.

⁴ Joseph Barrell, "A Century of Geology; The Growth of Knowledge of Earth Structure," *Amer. Jour. Sci.*, Vol. XLVI (1918), p. 162.

⁵ J. P. Buwalda, "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *Ida. Bur. of Mines and Geol. Pamph.* 5 (1923), p. 2.

⁶ Virgil R. D. Kirkham, "Oil Possibilities and Drilling Activities in South Idaho," *Ida. Eng.*, Vol. II, No. 1 (December, 1924), p. 11.

⁷ Arthur M. Piper, "Geology and Water Resources of the Bruneau River Basin, Owyhee County, Idaho," *Ida. Bur. of Mines and Geol. Pamph.* 11 (1924).

As has already been stated, the name "Snake River downwarp" was applied to the depression in a publication,¹ in January, 1927, and listed as a section heading for that paper. The writer believes this use, in a specific sense, is as fully justified as is the use of geosyncline for the Appalachian trough. The word "downwarping" has recently come into general use in papers by structural geologists and has been used extensively by R. T. Chamberlin, Bailey Willis, C. K. Leith, G. R. Mansfield, and others.

The writer suggests that subsiding areas, all of which may be genetically similar and products of secular subsidence, may be classified under four heads:

1. *Geosynclines*, located on continents, relatively lineal and narrow, generally marginal, progressive sinking, and deposition of marine shallow-water and terrestrial sediments. Type—Appalachian geosyncline.

2. *Mediterraneans*, located close to, and between contiguous continents, relatively irregular; deposition chiefly deep-sea rather than shallow-water sediments accumulating slowly. Type—Mediterranean Sea.

3. *Fore deeps*, located in oceans, relatively lineal and narrow, mostly marginal, deposition not shallow-water but deep-sea sediments accumulating slowly. Type—Tuscarora deep.

4. *Downwarps*: (a) Continental, located on continents, may have any orientation, relatively irregular or basin-shaped, progressive sinking and deposition of terrestrial sediments with or without extrusion or intrusion of lava sheets. Type—Snake River downwarp. (b) Oceanic, located in oceans far from continents, may have any orientation relatively irregular or basin-shaped, deposition slight, with or without extrusion of lava. Type—Cape Verde basin.

DEVELOPMENT OF THE "SUBSIDENCE" IDEA FOR THE SNAKE RIVER DOWNWARP

King,² in 1878, said:

Severe crumpling, as already mentioned took place, and the mountainous country east from the eastern boundary of Pah-Ute Lake, which must have been on the meridian of 117°, became depressed so that the lake, at the beginning of

¹ *Ibid.*

² Clarence King, *U.S. Geol. Expl., Fortieth Par. Rept.*, Vol. 1 (1878), pp. 412, 440.

the Pliocene deposition, stretched from the base of the Sierra Nevada to the base of the Wasatch, making a surface of eight degrees of longitude. The northward extension of this lake must have been far up the Upper Columbia River, while its southward extent is at present unknown. For this lake, occupying the whole breadth of the present Great Basin and parts of Idaho and Oregon, I propose the name Shoshone Lake.

Further on, he said:¹

The entire Great Basin area sank and became the receiver of the waters of an enormous lake, covering much of Nevada, Idaho, eastern Oregon and a part of California. The feature of general gentle subsidence and enlargement of lake area is common to the eastern and western post-Miocene disturbance.

From these statements it is clear that the first geologist in the region recognized it as a depressed area and a site of extensive lacustrine deposition. In speaking of the tilted and warped attitudes of the beds in the area, he said further:²

At the close of the Pliocene the last prominent dynamic events occurred. Both in the region of the eastern and western Pliocene lakes, wide areas were thrown into the attitude of inclined planes without either fault or fold. . . . This wide inclined tilting of sheets was executed without a fault or a rupture.

These statements indicate that he believed the disturbance to be very gentle and not connected with faulting.

Lindgren³ described this depression thus:

The Snake River Valley stretches across the whole width of southern Idaho in a broad curve opening toward the north and having a radius of 160 miles. The length of the valley from the base of the Tetons to Weiser, where the river enters into a narrow canyon, is over 400 miles, while its width ranges from 50 to 125 miles. Its total area being about 34,000 square miles. . . . On both sides of this valley rise higher ranges, chiefly of granite in the lower valley, of granite and Paleozoic and Mesozoic rocks in the upper valley. The lower slopes of these ranges are often flanked by Tertiary lake deposits. The larger part of the valley is occupied by vast flows of basalt, frequently resting upon and covered by fluvial and lacustrine accumulations contemporaneous with the flows. . . .

The mountains of older rocks surrounding the tectonic trough of the Snake River rise gradually, on the north side of the river. . . .

Before the beginning of the Neocene the chief features of the topography were outlined—the broad uplift of the Boise Mountains and the depression of

¹ *Ibid.*, p. 756.

² *Ibid.*, pp. 757, 758.

³ Waldemar Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part III (1898), pp. 625-736.

Snake River Valley. The latter is not unlikely a sunken area separated by old fault lines from the mountains to the north. At that time the basalt flows and lake beds did not exist. . . . Thus the time immediately preceding that from which the first records date was one first of uplift and subsidence; second, one of long-continued erosion, during which the Boise Mountains were dissected and the débris from the excavated canyons deposited in the basin of the Snake River Valley.

He made it clear that he believed the basin to have been formed by faulting before the basin beds were deposited in a lake which he called Lake Payette, whose highest level was placed at 4,200 feet because that was the highest point where he found lake-bed remnants. He believed the beds to have today essentially the positions and elevations of their deposition, regarding the slight dips noted at places in the lake beds as essentially initial dips, caused by deposition on a sharply sloping surface.¹ Lindgren,² in 1904, said:

During early Tertiary time the valley must have formed a broad and deep depression, north of which the mountains of central Idaho rose with an abrupt scarp, very probably due to faulting. Toward the south rose narrow, isolated mountains, like the Owyhee Range, with abrupt, deeply eroded outlines and with the general trend and character of the desert ranges of the Great Basin, of which, in fact, they are the most northerly outliers. The whole indicates an early Tertiary or pre-Tertiary fault differentiating the central Idaho mass from the area of fractured and dislocated blocks lying farther south. . . . No lava flows had yet covered the eroded flanks of the granite mountains. . . . It probably follows that a large part of this region has been depressed since the eruption of the lava, for the depth of the valley sediments near Weiser (elevation, 2,100 feet), as proved by borings, is more than 1,200 feet. . . . Even assuming that the above figure represents the deepest point of the valley (which is not probable) it would place the bottom only 1,000 feet above sea level.

It is clear from the foregoing statement that Lindgren believed the depression to be due to faulting and to have been formed prior to the extrusion of the Columbia River basalts and deposition of any lake beds. Although, in 1898, he saw no evidence for disturbance or subsidence after the deposition of the lake beds, he recognized, by 1904, that subsidence on a small scale may have occurred.

¹ Waldemar Lindgren, "Description of the Boise Quadrangle," *U.S. Geol. Surv. Geol. Atlas Folio 45* (1898), p. 3.

² Lindgren, "Descriptions of the Silver City Quadrangles," *U.S. Geol. Atlas Folio 104* (1904), p. 1.

The writer¹ described the downwarp for much of its area in southeastern Idaho in January, 1927, as follows:

The great structural depression which lies in the southeastern half of the mapped area extends beyond the boundaries to the east and the southwest. It is now partly occupied by the Snake River lavas and the interbedded gravels and lake beds. The assumed axis of this trough extends from a point on the map edge directly south of Mud Lake northeasterly to Camas thence in the direction of Camas Creek northeastward. The Plain region at its widest part in the mapped area is about 50 miles across, not counting the wide valley reentrants. Its average width, in the area, measured at right angles to the axis, is nearly 45 miles.

As has been described under physiographic development, the outline and extent of this structural depression is marked by the Pliocene (?) acidic lavas (described under igneous rocks as Tertiary Late Lavas) and interbedded continental deposits.

These acidic lavas and associated interbedded continental sediments, as has already been mentioned, dip gently toward the edge of the plain, on all sides. Figs. 2 and 3 are sections showing the relationships existing from Medicine Lodge Creek to Henry's Fork along the northern edge. The structural relief here is often as much as 4,000 feet. In other parts of the plain area, especially along the east and southeast, the relations are the same but the relief is less (see photographs A and B, Plate I).

A slope of 4 to 5 degrees represents the angle of dip about the periphery of the Plain. At many places on the southeastern edge of the Plain the lava rises less than 2,000 feet above it on the noses of the ranges and to a lesser distance in the intervening structural valleys. How far these acid lavas continue their dip beneath the Snake River basalt is of course conjectural but in a structural valley whose average width is 45 miles a great vertical distance might be reached before flattening out takes place. To assume that the acidic series lies more than 2,000 feet deep in the center of the Plain, in this area, would not seem unreasonable. A distance twice this great is not unthinkable.

It is believed that the subsidence which took place in these relatively flat-lying widespread acid lavas was accompanied by an upward tilting of the regions adjacent to the area. This expression to the north is represented by the Centennial Range geanticline or uplift whose axis parallels the topographic axis of the Centennial Range. It gradually dies out as it extends westward across the Beaverhead, Lemhi, and Lost River ranges and their intervening valleys.

Although upward movement was exerted southeast of the Plain, it was from several hundred to a few thousand feet less than that north of the Plain. Some

¹ Virgil R. D. Kirkham, "A Geological Reconnaissance of Clark and Jefferson and Parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 19* (January, 1927), pp. 24, 25, 26.

possible physiographic effects of the subsidence and complementary uplifts are discussed under the section on physiographic history.

It must be understood that in using the expression "downwarp" the writer does not mean to infer that minor faulting or small step-faults did not occur. It would seem a physical impossibility to move any widespread rigid sheet of material, which was so thin in comparison to its extent, without causing minor breaks and displacements.

Step-faults and slumpings of a few feet displacement should be abundant, but great block faults with several hundred feet displacement need not necessarily be assumed in this part of the Plain. No doubt, breaks of some magnitude occurred in the bottom of this depression. From these probably exuded the Snake River basalts along rifts now represented by chains of cones. These, however, at every place studied are more common near the center of the Plain than near the edges where they would be if great block faults formed the Plain borders. Only two hot springs lie within 25 miles of the Plain borders and these, located at Heise and Lidy Hot Springs, are associated with older major mountain faults which approach the Plain edge at a right angle.

In brief, the evidence, here as well as elsewhere, points overwhelmingly to a gently folded syncline of great proportions accompanied on either flank by a corresponding and complementary uplift. This appears to have been greatest to the north where an anticline much less in length and width was formed contemporaneously. The age of this movement was later than the Tertiary Late Lavas which are assigned a Pliocene (?) age on the strength of their relationship with the Salt Lake formation.

The writer,¹ in 1928, said, "the axes of the folds invariably plunge to the southeast down the flanks of the Snake River downwarp."

Bryan,² in 1929, said:

The first earth movement recorded in this area is the slight deformation that arched a ridge prior to the deposition of the Payette and Idaho formations. It seems likely that the production of this ridge was only a minor feature of a much larger disturbance by which the Snake River region on the north was carried below the volcanic plateaus on the south. Certainly at Ontario, 30 miles north of this area, the thickness of the Payette and Idaho formations is more than 4,000 feet, as shown by the log of a deep well, and only 8 miles north a well 1,140 feet deep has been drilled without striking the basalt. . . . This structure also is only one of the minor results of the greater movement by which the Snake River Basin was carried below the plateaus of southeastern Oregon and southern Idaho.

¹ Virgil R. D. Kirkham, "A Brief Preliminary Report on the Possibilities of an Underground Water Supply for the City of Weiser, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 29* (June, 1928).

² Kirk Bryan, "Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon," *U.S. Geol. Serv., Water-supply Paper 597 A* (January, 1929) p. 56.

The Payette beds of which he speaks are included in the Idaho beds of the writer in a recent paper.¹

A review of all the publications describing this depression shows that in 1878 King,² as a result of his hurried reconnaissance of this region, believed that the area had subsided without violence, developing gentle dips in the lavas and the lake beds.

Lindgren, in 1898³ and 1904,⁴ conceived the basin to have been formed by a series of immense faults previous to the deposition of the lake beds and lavas. He believed that uplift to the north was as effective as the downfaulting in creating the present relief. Dips in the basin lake beds were regarded as depositional. He thought the mountains to the north were separated from the basin by an abrupt scarp. This misconception was due to the fact that the relatively soft, dipping basin-beds have been truncated during two periods of lateral planation, and the tilted and uplifted granite surface to the north now presents a notable relief, visible at great distances. Actually, however, this "abrupt scarp" has a slope to the basin beds of about 8°, and the truncated basin beds and lava flows, before erosion, rested on this surface as shown in a previous paper on physiographic history.⁵

The Owyhee Mountains, whatever may be the structure in the older rocks, now represent an anticline or arch in the Columbia River lavas and the Owyhee rhyolite which dip away from its axis into the downwarp on the north and northeast and also to the southwest, and northwest. This indicates anything but basin-range structure, and no basin ranges lie within the map area.

Lindgren⁶ later revised his opinion to include some depression after the deposition of the lake beds and extrusion of the lava.

¹ Virgil R. D. Kirkham, "Revision of the Payette and Idaho Formations," *Jour. Geol.*, Vol. XXXIX, No. 3 (1931), pp. 193-239.

² King, *op. cit.*

³ Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge Idaho," *op. cit.*, pp. 625, 3.

⁴ Lindgren, "Descriptions of the Silver City Quadrangles," *op. cit.*, p. 1.

⁵ Virgil R. D. Kirkham, "Old Erosion Surfaces in Southwestern Idaho," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 653-58.

⁶ Waldemar Lindgren, and N. F. Drake, "Descriptions of the Nampa Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 103* (1904).

Russell,¹ in 1902, followed Lindgren closely but recognized the plains as a depressed area; he also believed the depression to have been formed prior to the deposition of the lake beds and the extrusion of the lavas. Part of the depression he assigned to erosion by a large river, but more of it to normal faulting on a large scale. The faulted areas which he presented as evidence are in the uplifted intermontane regions north of the downwarp and comparatively remote from the basin proper. The lavas on the high ridge at the north line of Gooding County lie at an altitude of 6,800 feet, and from there the rhyolite flows dip steeply at from 12° to 15° southward to the plains where they dip under the later Snake River basalt. Russell noted this dip to the plains from Clover Creek to Ada County, and recognized it as part of an area warped with the axis along the valley. In 1903² he wrote at length of this structural warp, describing the in-dipping beds in the Lewis artesian basin, and extending the length of the downwarp into Malheur County, Oregon. He had apparently recognized, by 1903, that faulting was not the major influence in developing the basin, since he failed to mention it in his text when describing conditions in the basin beds. Washburne³ recognized the depression as a downwarp and noted the lack of faulting and folding. He was, however, in error in believing the syncline to terminate on the east against the Boise Mountains. Nearly all of his reconnaissance was in Oregon where the axis of the downwarp is nearly east and west; the axis in Idaho instead of terminating, merely changes direction and trends southeast and northwest (see Fig. 1). It changes again at Hammett and Glenns Ferry and runs northeast and southwest to Yellowstone National Park. Washburne noted the steep dips near the mountains and the increasingly lower dips farther out in the plains.

Buwalda,⁴ in 1921 and 1923, described the downwarp in its true

¹ I. C. Russell, "Geology and Water Resources of the Snake River Plains of Idaho," *U.S. Geol. Surv. Bull.* 199 (1902).

² I. C. Russell, "Preliminary Report on Artesian Basins in Southwestern Idaho and Southeastern Oregon," *U.S. Geol. Surv. Water-Supply Paper* 78 (1903).

³ C. W. Washburne, "The Marine Sediments of Eastern Oregon," *Jour. Geol.*, Vol. II (1903), pp. 224-290.

⁴ J. P. Buwalda, "Oil and Gas Possibilities of Eastern Oregon," *Ore. Bur. of Mines and Geol.*, Vol. III, No. 2 (1921); "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *op. cit.*

light, and understood the full significance of the evidence presented. The writer accompanied Buwalda on his 1920 reconnaissance of southwestern Idaho and at once accepted his conception of the downwarp as a sinking area from the incontrovertible evidence presented in the field. Reconnaissances by the writer, in southern and southwestern Idaho during 1921-25, showed that the same solution applied equally well to the rest of the depression. Ten weeks field work, on the eastern part of the downwarp in 1926, showed that at every place the rhyolite, called "Tertiary Late Lavas" by the writer,¹ dipped in toward the axis of the downwarp. Erosion in the Snake River basalt shows that the rhyolite underlies it in the plain area. Eight weeks in the downwarp region, in 1927, served to link up the southwestern section and the southeastern section, and made clear that the downwarp was a continuous structural feature from Yellowstone National Park to Vale, Oregon, which was flanked on each side by practically parallel gently folded arches.

Work by Piper,² in 1924, and by Piper and the writer,³ in 1926, served to confirm earlier reconnaissances of the writer for southern and southeastern Idaho. In all, the writer spent twenty-six weeks in the field on the map area, and approximately twenty-seven weeks in field work on the downwarp outside the map area, in connection with economic investigations.

EVIDENCE OF DOWNWARP

Field evidence is sufficiently strong for every worker in the field to recognize that the Snake River plain area is a "subsidence," "trough," "depression," "syncline," "fold," "warp," or "downwarp."

The formations which obviously take part in the downwarp in southwestern Idaho are in order of their age: the lower series of the Columbia River basalt of Miocene age, the terrestrial Payette formation of Middle and Upper Miocene age, the upper series of the Columbia River basalt of Upper Miocene age, the Owyhee rhyolite

¹ *Op. cit.*

² Arthur M. Piper, "Geology and Water Resources of the Bruneau River Basin, Owyhee County, Idaho," *op. cit.*

³ A. M. Piper and Virgil R. D. Kirkham, "Groundwater for Municipal Supply at Idaho Falls, Idaho," *Idaho Bur. of Mines and Geol., Pamph. 16* (1926).

of Upper Miocene or Lower Pliocene age, the terrestrial Idaho formation of Pliocene and Pleistocene age, the terrestrial Upper Mesa formation of Pleistocene age, the Snake River basalt of Pleistocene age, and the terrestrial Lower Mesa formation of Pleistocene age.

In southern and southeastern Idaho, the Columbia River basalt is absent. The Salt Lake formation commonly described as of Pliocene (?) age lies in the same position in relation to the rhyolite as does the Payette formation in southwestern Idaho, and, although no definitive flora or fauna from it has as yet been determined, it may even-

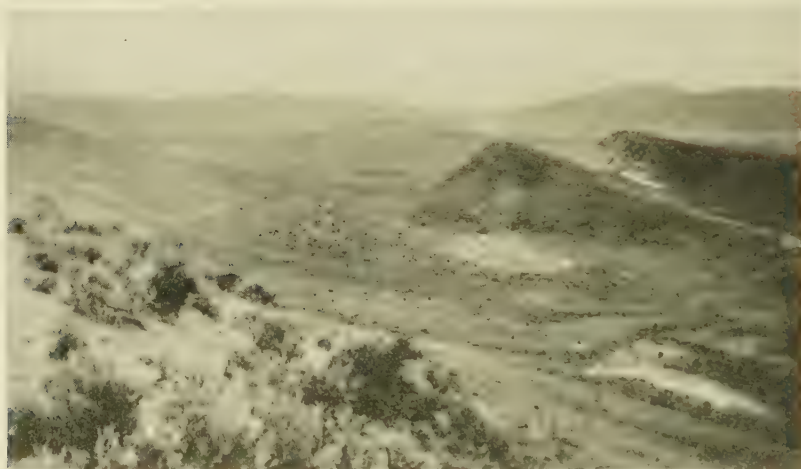


FIG. 2.—Looking southeast along the strike of the Idaho lake beds which dip southwest to the downwarp axis near Alkali Creek on the north side of the downwarp.

tually prove to be contemporaneous with the Payette formation. The extensive rhyolite series of southern and eastern Idaho which takes part in the downwarp is the same for the most part as the Owyhee rhyolite of southwestern Idaho. The Idaho formation overlying this rhyolite extends as far east as Buhl. Several isolated deposits of gravels and clays which overlie the rhyolite and which underlie, or are interbedded with, the Snake River basalt may be contemporaneous with the Idaho formation in southeastern Idaho. The Snake River basalt in southeastern Idaho is chiefly Pleistocene in age, but some of the lower flows, which are now buried, may be Pliocene in age.

The evidence, much of which has been given in detail in a former paper¹ consists of tilted or dipping lava flows and lake beds (see



FIG. 3.—Idaho lake beds dipping gently to the downwarp axis from the south side. These are characteristic of the upper members.

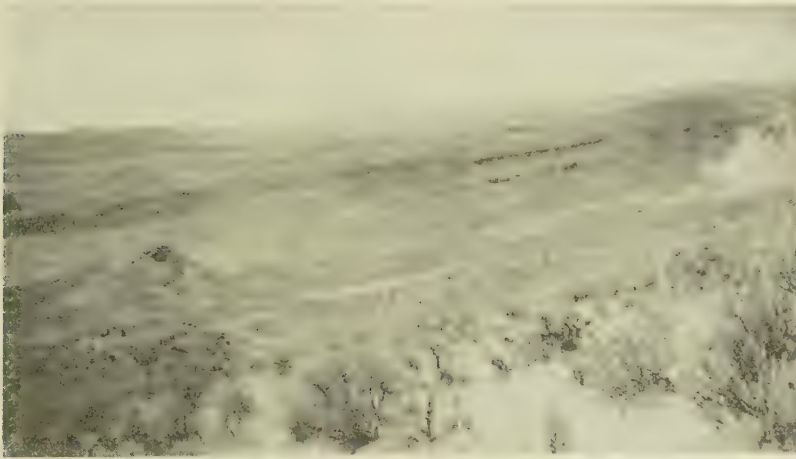


FIG. 4.—Idaho beds in the Weiser quadrangle dipping southwest to the axis of the downwarp.

Figs. 2, 3, 4, 5, and 6). In the map area (see Fig. 6) the Columbia River basalt lies on both sides of the downwarp and dips toward the

¹ Virgil R. D. Kirkham, "Revision of the Payette and Idaho formations," *op. cit.*

axis (see Figs. 7, 5, 8, 6, 9). The Owyhee rhyolite lies on both sides of the downwarp and dips toward the axis also (see Figs. 7, 8, 6). The Payette formation lies on both sides of the downwarp and dips toward the axis (see Figs. 7, 8, 6). The Idaho formation lies in the present basin area and the lowermost members dip toward the axis (see Figs. 7, 8, 6 and Figs. 4, 10). Higher members dip toward the downwarp axis at lower angles and so on (see Fig. 2) until the upper members in the central part of the basin lie in an



FIG. 5.—Payette beds under the upper series of Columbia River basalt in Linson Valley.

almost horizontal position (see Figs. 7, 8). The Upper and Lower Mesa formations and the erosion flats upon which they lie dip at slight angles toward the downwarp axis, as described in a former paper.¹ All dips in the Idaho formation were secured by plane-table sections crossing the strike of the beds. These were carefully ascertained in order to detect the very gradual change of dip. The old pre Columbia River basalt peneplain on the granite also dips toward the downwarp axis from each side of the plain, as previously described. That the lake beds were nearly horizontal when deposited is indicated by the bedding planes, ripple marks, and character of the cross-bedding. Thin, but widespread, ash beds, diatomite

¹ Virgil R. D. Kirkham, "Old Erosion Surfaces in Southwestern Idaho," *op. cit.*, pp. 652-63.



LEGEND

 Alluvium

PLEISTOCENE
 Lower Mesa Gravels
 0.1 - 0.2 m.y.
 0.1 - 0.2 m.y.

PLEISTOCENE
 Upper Mesa Gravels
 0.1 - 0.2 m.y.
 0.1 - 0.2 m.y.

PLEISTOCENE and PLOCIENE
 Snake River Basalt

PLOCIENE (?)
 Rhyolite

PLOCIENE (?)
 Idaho Formation

MIocene (?)

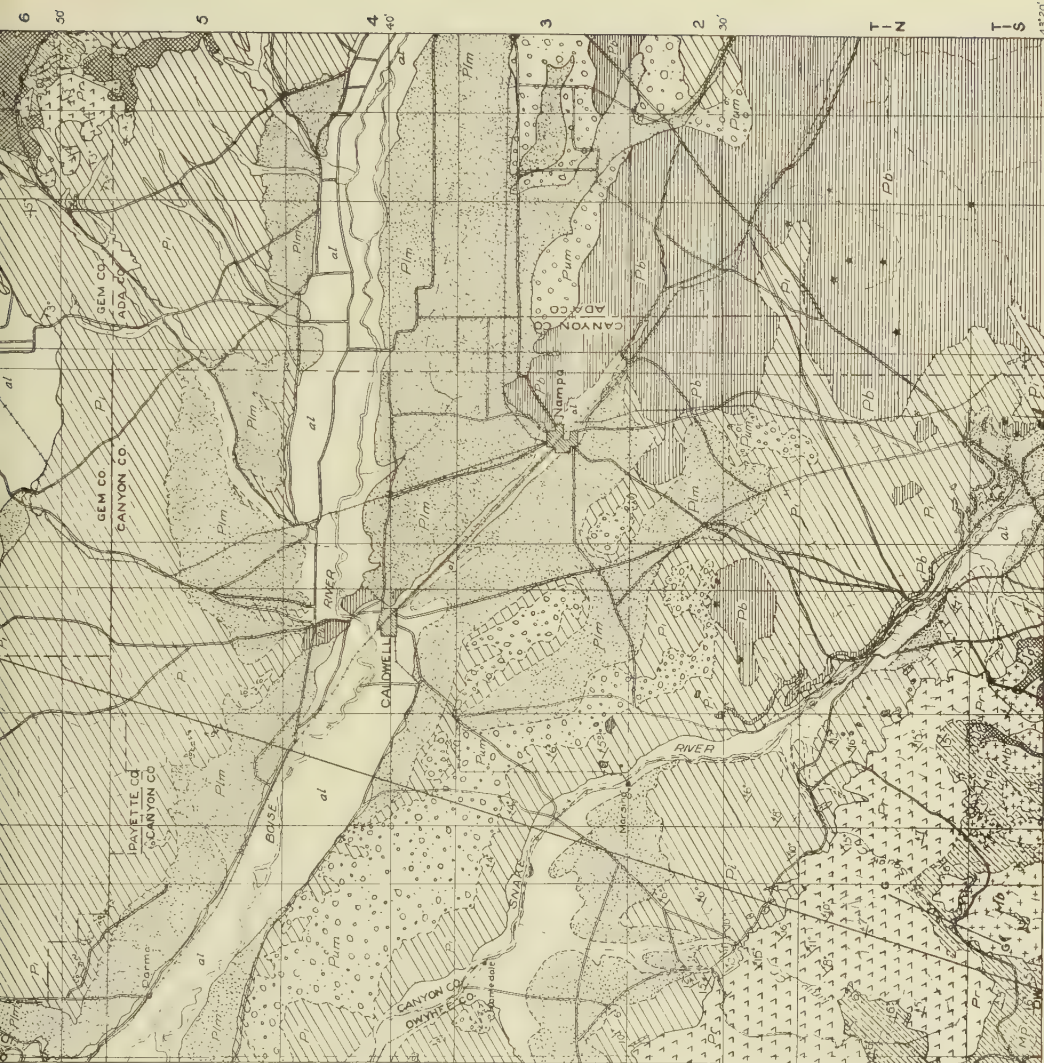


FIG. 6

- Granitic Intrusive (dike batholith)
- TRIASSIC (?)
- Sediments and Volcanics (metamorphosed)
- PERMIAN
- Volcanics
- ANTICLINAL AXIS
- SYNCLINAL AXIS
- DIP AND STRIKE
- LAVA VENTS

Township Diagram

6	5	4	3	2	1
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36

Scale of miles
 0 1 2 3 4 5 Miles
 0 1 2 3 4 5 Miles

GEOLOGIC MAP OF CANYON, GEM, PAYETTE, and parts of ADA, ADAMS, OWYHEE, and WASHINGTON COUNTIES, IDAHO

Aerial Geology by Virgil R. D. Kirkham
 Supplemented by computations with published maps of Wilderness Landgram,
 and others of the U.S. Geol. Survey, and D.C. Livingston

Structure and Stratigraphy by
 Virgil R. D. Kirkham

SCALE
 0 1 2 3 4 5 Miles
 0 1 2 3 4 5 Miles

beds, and carbonaceous seams deposited in flat-lying positions are now tilted at angles too high to be depositional.

As shown in a former paper,¹ the dips indicate a thickness of more than 18,000 feet of Idaho formation alone; beneath these beds lies

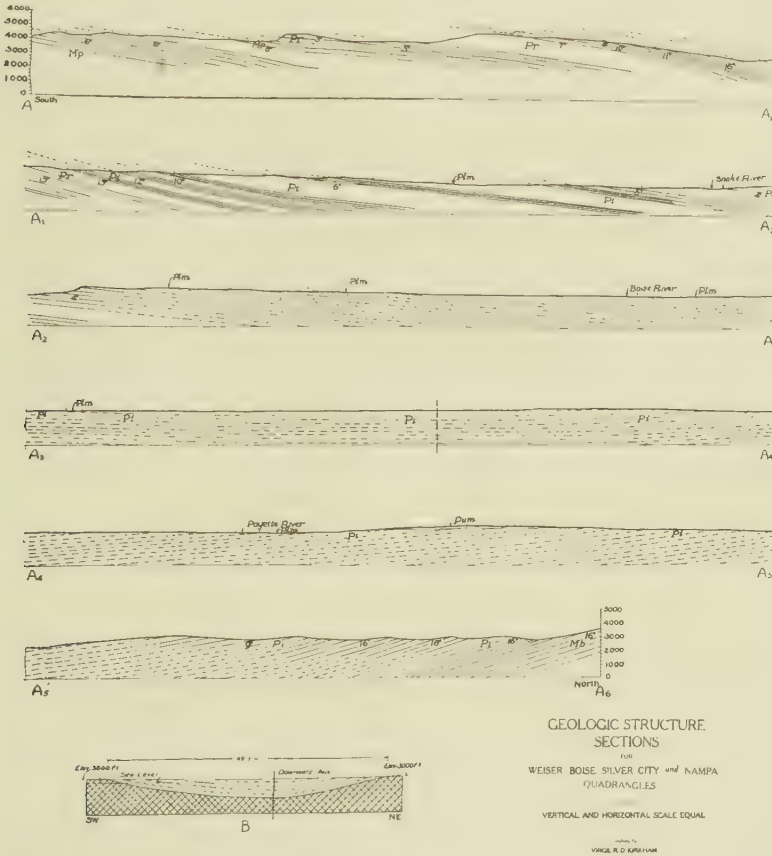


FIG. 10.—*Mp* is the Payette formation, *Pr* is the rhyolite series, *Pi* is the Idaho formation, *Plm* is the Lower Mesa formation, and *Pum* is the Upper Mesa formation. *Mb* is Columbia River basalt.

the Owyhee rhyolite which is over 1,900 feet thick at places south of the plain and 700 feet thick north of the plain. Underlying the rhyolite is a variable thickness of Columbia River basalt which averages 2,000 feet in thickness south of the plain and attains thicknesses

¹ "Revision of the Payette and Idaho formations."

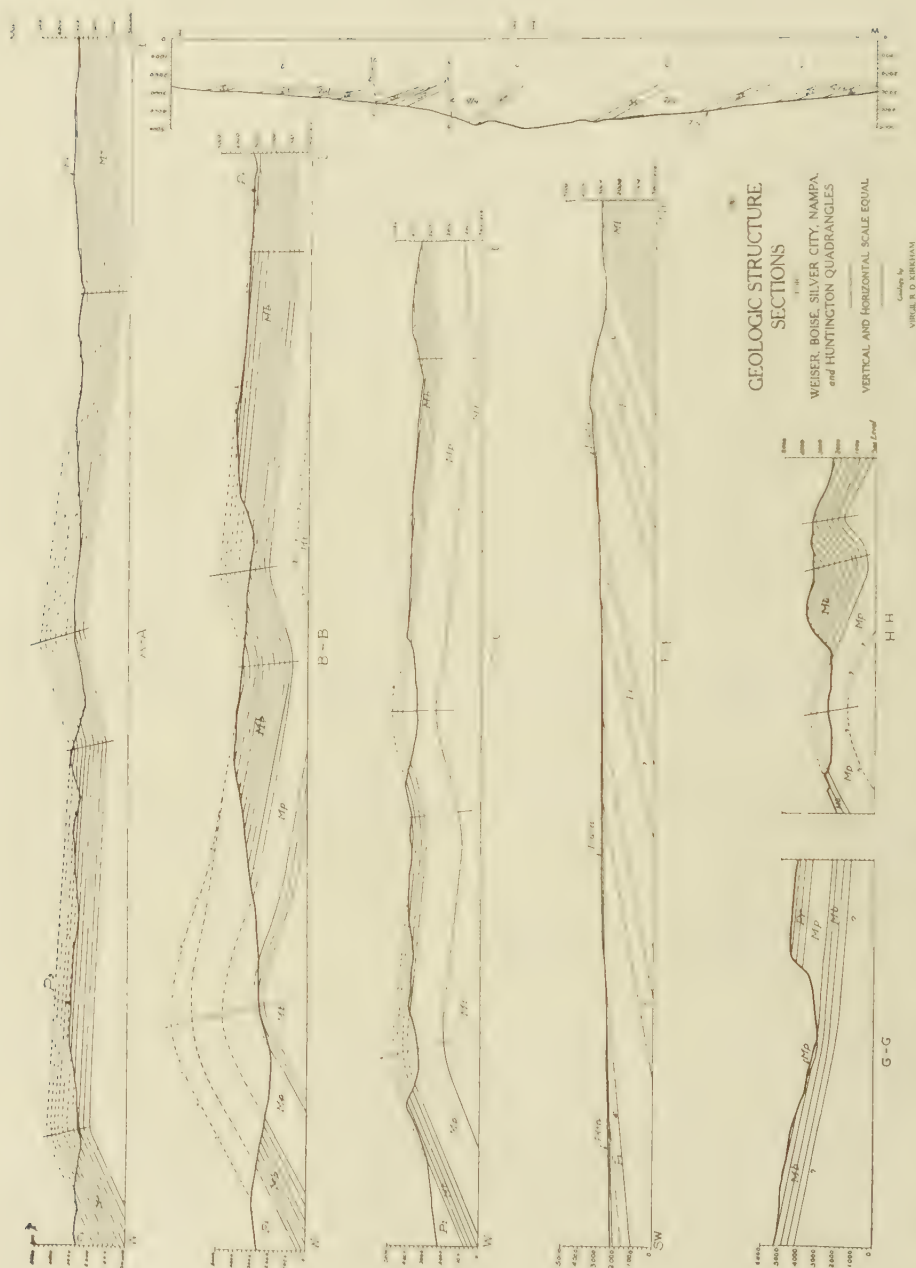


FIG. 2.—*M_b* is Columbia River basalt, *P_i* is Idaho formation, *P_{um}* is the Upper Mesa formation, *P_{lm}* is the Lower Mesa formation, *P_r* is the rhyolite series. *M_b* is the Payette formation.

much greater north of the plain; interbedded with this are 900 or 1,000 feet of Payette formation (see Figs. 11, 5, 12, 9).

That these formations extend beneath the plain's area is strongly suggested by their presence on both sides and their relations to each



FIG. 5.—Looking north on Little Squaw Creek at the Owyhee rhyolite overlying the Payette lake beds in the middle, and Columbia River basalt underlying the Payette in the foreground.

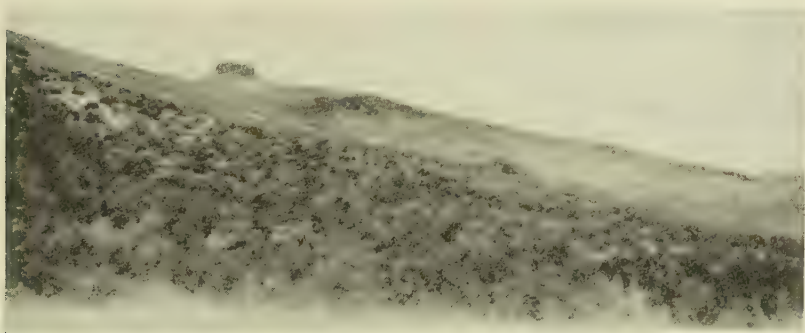


FIG. 10.—Idaho beds in the Nampa quadrangle overlying the rhyolite and dipping toward the downwarp axis to the northeast. Note the irregular surface of the rhyolite projecting through the lake beds.

other and the Idaho formation. The sections of Owyhee rhyolite and Columbia River basalt, exposed on each side, have suffered much erosion before and since the deposition of the Idaho and may not represent their original thicknesses. A compilation of these

thicknesses suggests that the pre-Columbia River basalt peneplain may have been downwarped to a point between 19,000 and 21,000 feet below sea level. A well at Ontario, Oregon, actually passes

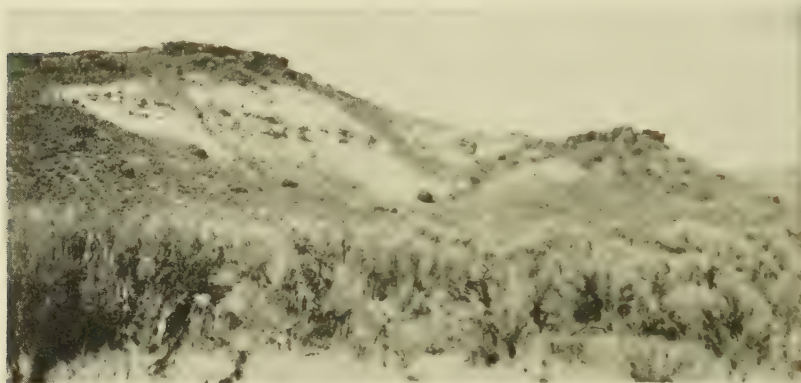


FIG. 11.—Payette beds dipping under the Owyhee rhyolite cap toward the down-warp. The small patch of rhyolite on the right has slumped from the main mass.

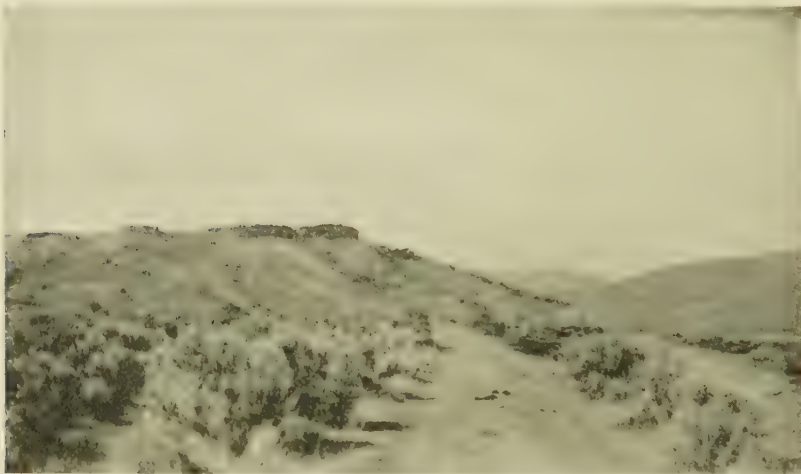


FIG. 12.—Looking northeast at the Payette formation in the Silver City quadrangle, dipping northeast under the Owyhee rhyolite which caps it.

through the Idaho formation to a point 2,300 feet below sea level, and has not entered the Owyhee rhyolite which should lie below. Under this should be the Payette formation and the Columbia River

basalt. If the well should enter rhyolite at once, which is unlikely, and these formations are present with thicknesses comparable to those now exposed on the flanks, the minimum depth at Ontario, for the granite peneplain, would be over 7,000 feet below sea level. Although terrestrial deposits are now accumulating in regions below the present sea level, as in Death Valley, California, it seems unlikely that accumulations such as those represented by the great thicknesses of the Payette and Idaho formations could have been formed in such a situation. It is reasonable to infer that the present position of these formations, far below sea level, is due to subsidence which, in this case, occurred by downwarping.

In all parts of the downwarp the lavas dip toward the axis as they do in the map area. This area, however, affords evidence, because of the continuous deposition of the lake-bed and terrestrial sediments, of the steady and progressive sinking of the area. In the regions where the lavas welled forth rapidly with great time intervals between extrusions, the downwarping is equally obvious, but no measure of its progress is at hand. Thus in eastern Idaho the rhyolite is notably tilted, but the intervening time interval before the extrusion of the Snake River lava was apparently so great that the latter overlies the rhyolite at most places with angular unconformity. This may not be true of earlier flows now buried, but the present surface flows at the edge of the basin are practically horizontal and abut against the warped rhyolite dip slopes.

Outside the map area the rhyolite and the interbedded or underlying Salt Lake formation of Pliocene (?) possibly Upper Miocene (?) age are the key formations indicating the downwarping. These were certainly deposited and extruded nearly horizontally and now lie in an unbroken fringe around the northeast, east, southeast, and south flanks of the downwarp. The rhyolite and interbedded Salt Lake formation dip toward the downwarp axis at angles varying from 5° to 20° .

The acidic lava series called "Tertiary Late Lavas," originally had a widespread occurrence and extended over the Snake River, Caribou, Blackfoot, Goose Creek, and Sublette ranges and many others as well. These ranges have been notably uplifted vertically since the extrusions of these flows and the lava now dips away from

the tectonic axes. These ranges are folded anticlinoria and thrust-fault slices which form definite, nearly parallel, units of the Rocky Mountain structure. The age of the folding is chiefly post-Lower Cretaceous,¹ and most of the thrust-faulting is certainly pre-Eocene. During Pliocene times these ranges were tilted and now plunge below the acid lavas and Snake River basalt, where the downwarp crosses them. The acidic lava on these ranges is found at elevations as high as 8,800 feet. The same flows dip under the basalt of the plain in a distance of less than 10 miles at an elevation of 4,500 feet above sea level. The acidic lava extends far up the synclinal depressions parallel to the tectonic axes of the mountains. At several places it extends 20 miles farther back from the basalt of the plains than it does on the summits of the ranges from which most of it has been removed by erosion. Whether in troughs between ranges or on the noses, the acidic lava always dips under the basalt of the plains. Erosion by the South Fork and North Fork of Snake River shows that it underlies the basalt far out in the plain. That the dip of the acidic lava is not the angle of flow is indicated by the interbedded sediments and tuffs and ash beds of the Salt Lake formation which were deposited nearly horizontally but now dip concordantly with the rhyolite.

Evidence that the rhyolite underlies the basin-filling of Snake River basalt is found at many places where the Snake River has cut through the basalt, as at Shoshone Falls, Big Falls, or American Falls.

From Birch Creek to a point west of Hailey, on the north side of the downwarp, occur a series of ranges of thrust slice-blocks such as Beaverhead, Lemhi, and Lost River ranges. These ranges, like those on the south, intersect the downwarp at a high angle and like them, plunge beneath the rhyolite which, in turn, dips under the basalt of the plain. The acidic lava fringe has been removed by stream erosion from the valleys between the ranges, but remnants still remain on the nose of each range. At some places the plunge of the range reaches an angle of 7°. This amount of tilting is similar to that recorded by the peneplain on the granite in the map area.

¹ Virgil R. D. Kirkham, "Geology and Oil Possibilities of Bingham, Bonneville, and Caribou Counties, Idaho" *Ida. Bur. of Mines and Geol. Bull.* 8 (1924).

It is thus clear that the downwarp crosses the tectonic axes of the main ranges of the Rocky Mountains in southeastern Idaho. These ranges have been tilted bodily, and now plunge to the downwarp axis from each side.

Another curious proof of the warping exists in southeastern Idaho. More than a dozen old cones, from which the rhyolite was extruded, still exist on the tilted rhyolite slope which surrounds the downwarp. As one would expect, all of these cones now stand perpendicular to their warped base and markedly tilt toward the valley. For further substantiating details concerning the evidence outside the map area the reader is referred to several former papers of the writer.¹

CAUSE OF DOWNWARPING

That the downwarp is a result of vertical subsidence due to deep-seated flowage or adjustment of magma rather than a result of compressive forces, is strongly supported by the fact that the downwarp, for half of its length, is superimposed on the westernmost ranges of the Rocky Mountain system in a direction practically normal to their tectonic axes. Proof of this superimposition lies in the fact that great overthrust faults, anticlinoria, and tectonic axes all plunge beneath the downwarp axis on each side.

Subsidence due to the removal of underlying supporting elements, could have accomplished this phenomenon, but it hardly seems conceivable that compressive forces, applied normal to the downwarp axis and parallel to the tectonic axes, would not have been expressed in arching or vast lateral or strike movements along the planes of the long and essentially parallel overthrust faults rather than in subsidence.

At no place along the downwarp was the warping initiated until after the extrusion of the thick and widespread Columbia River basalt series and the equally widespread but less thick series of acidic flows called the Tertiary Late Lavas.

It seems possible that the extrusion of both of these lava series over the area now occupied by the downwarp and adjacent areas may have caused a diminution of the underlying support of a considerable area which resulted in the initiation of subsidence. The

¹ *Bull. 8, and Pamphs. 16 and 19, Ida. Bur. of Mines and Geol., Moscow, Idaho.*

accumulation of sediments and lavas in this incipient depression undoubtedly contributed to further subsidence, as did other factors.

SUMMARY

The widespread, relatively thin sheet of rhyolite lava called "Tertiary Late Lava" and represented by the Owyhee rhyolite in the map area, is everywhere affected by the downwarp or the uplift in the adjacent regions. The Rocky Mountain ranges on either side of the downwarp plunge toward the downwarp axis which crosses them normal to their tectonic axes. In the western part of the downwarp, thousands of feet of sediments collected gradually with the continued sinking. In the eastern part were extruded great thicknesses of Snake River basalt, which partially filled the depression.

The downwarp being apparently a region of structural weakness probably has faults or rifts in its bottom and sides. At some places the smooth, warped dip slopes are broken by small discontinuous faults; these usually are expressed in lavas underlain by soft, relatively unconsolidated lake beds and result from compaction, slumping, and spalling, and are technically landslides. No faults approaching the magnitude of those of the Basin Ranges or the north and south fault-block ranges, which occur north and south of the downwarp in Idaho, occur, bounding the plains area, as postulated by Lindgren and Russell. Stratigraphic and structural units and physiographic surfaces have been correlated with certainty across the downwarp and this indicates their probable existence below the present plain surface at great depths.

IGNEOUS GEOLOGY OF SOUTHWESTERN IDAHO¹

VIRGIL R. D. KIRKHAM
Saginaw, Michigan

ABSTRACT

The known igneous history of southwestern Idaho began with the deposition of a great thickness of Permian andesites and rhyolite. Following this in Jurassic (?) time occurred the intrusion of the Idaho batholith. After an extensive erosion interval followed the extrusion of the lower series of Columbia River basalt. During a period of quiescence the Payette formation was deposited. This was followed by the extrusion of the upper series of the Columbia River basalt upon which was developed a peneplain-like erosion surface. Before the deposition of the Idaho formation the Owyhee rhyolite was extruded, which is part of a widespread sheet of acidic lavas which extends over southern Idaho and parts of adjacent states. Probably contemporaneous with these acid flows occurred the intrusion of one or more small batholiths into the Payette formation and Columbia River basalt. Down-warping was initiated, and upon the upper series of the Columbia River basalt and the Owyhee rhyolite was deposited the Idaho formation in Pliocene time. The Snake River basalt was extruded into the downwarp to the east in Pliocene and chiefly Pleistocene time, and it encroached on the Idaho formation in southwestern Idaho in the Pleistocene.

INTRODUCTION

The data and conclusions presented in the following pages are results of field work undertaken for the Idaho Bureau of Mines and Geology in executing economic investigations. The writer spent eight weeks of field work on parts of the area in 1920, and the main regional stratigraphic and structural implications were gained at that time. These were amply confirmed by subsequent more detailed work which constituted a week's work in November, 1921; a week's work in 1926; and four weeks' in 1927. Finally, the earlier results were enriched and amplified by twelve weeks of detailed work on the map area in 1928. The bulk of the material presented herein has thus been under consideration by the writer for ten years.

ACKNOWLEDGMENTS

The writer acknowledges, with appreciation, aid from the Idaho Bureau of Mines and Geology, which financed the field work for this paper. Courtesies also were extended the writer by Dr. Francis A. Thomson, president of Montana School of Mines, former secretary

¹ This work was done in co-operation with the Idaho Bureau of Mines and Geology, and the results are published with the permission of the secretary.

of the Idaho Bureau of Mines and Geology; and Messrs. E. W. Ellis, A. W. Fahrenwald, and J. W. Finch, who have since served as secretaries of that organization. Thanks are due also to various members of the Department of Geology, University of Chicago, for valuable counsel and a careful reading and criticism of this manuscript. Able assistance was given in the field by Messrs. M. Melville Johnson, H. L. McKinley, and Clarence F. Myrene.

PERMIAN VOLCANICS

The writer was led into a reconnaissance of the area in which these rocks occur, in an attempt to find here Mesozoic or Paleozoic marine sediments which could act as the source for gas flows yielding gasoline which occur abundantly in the region around Payette and Ontario to the southeast. The study was sufficient to determine the nature of the rocks within the region and their structural relations, and thus accomplished the purpose of the investigation; but time was not sufficient to allow a careful study of the area as this contributed only indirectly to the chief problem under consideration. The writer found both structural and areal relations in substantial agreement with those outlined by Livingston¹ on Plate I, *Pamphlet 13*, and has consequently drawn on Livingston's work for the formation boundaries on the map.

Location.—Permian Volcanics are confined to the area west of the Weiser quadrangle (see Fig. 1), and are chiefly exposed in the gorge of Snake River and some of the canyons of the deeper tributaries. The southernmost exposure is a small inlier in the basalt in Secs. 5 and 8, T. 11 N., R. 7 W. A wider belt of these rocks appears in Sec. 20, T. 11 N., R. 7 W., and extends north to the limits of the area. The divide between Rock Creek and Snake River is capped by a relatively narrow strip of Columbia River basalt which conceals the Permian series at the surface.

The drainage area of Rock Creek lies chiefly in the Permian system, which is here bounded by an irregular rim of the overlying Columbia River basalt. The map contact of the Permian volcanics

¹ D. C. Livingston, "A Geologic Reconnaissance of the Mineral and Cuddy Mountain Mining District, Washington and Adams Counties, Idaho," *Idaho Bur. of Mines and Geol. Pamph. 13* (1925).

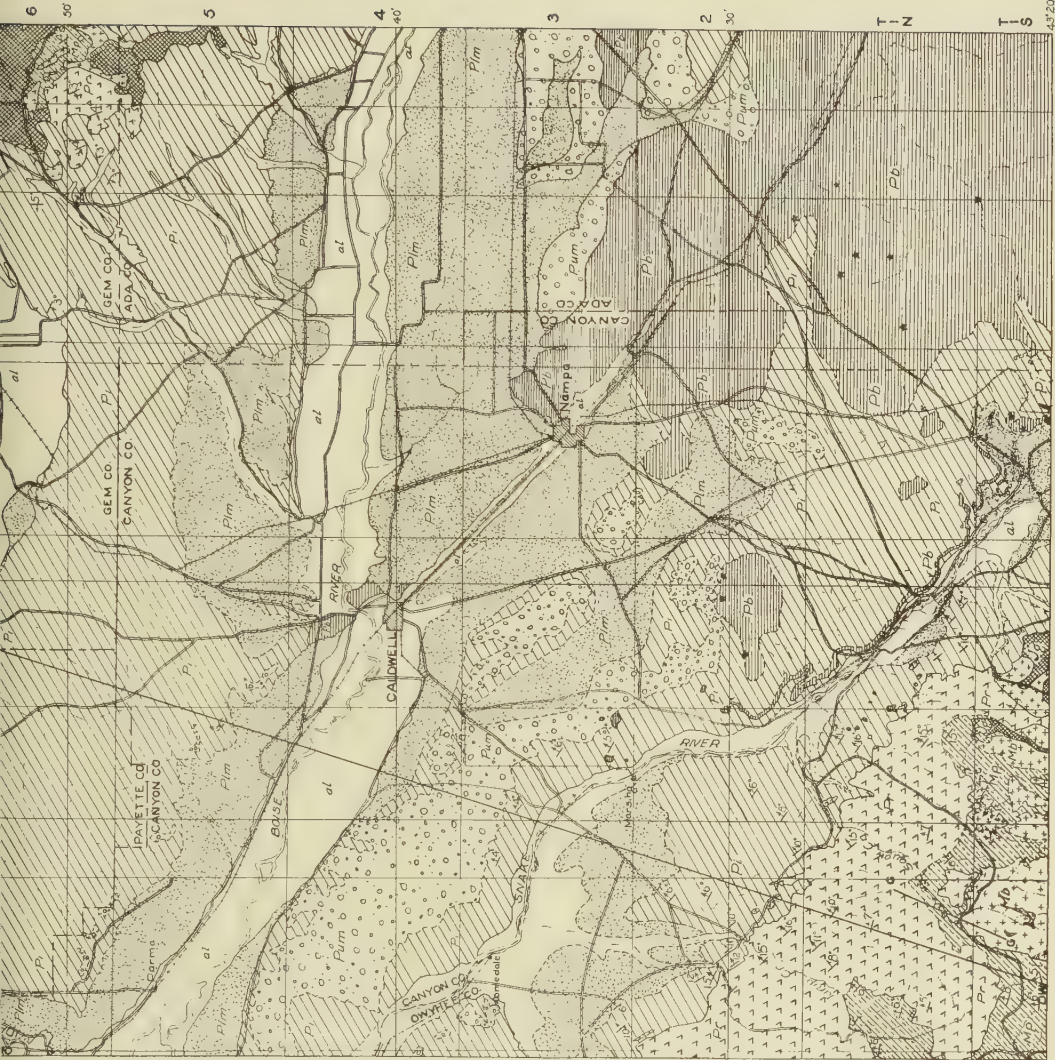
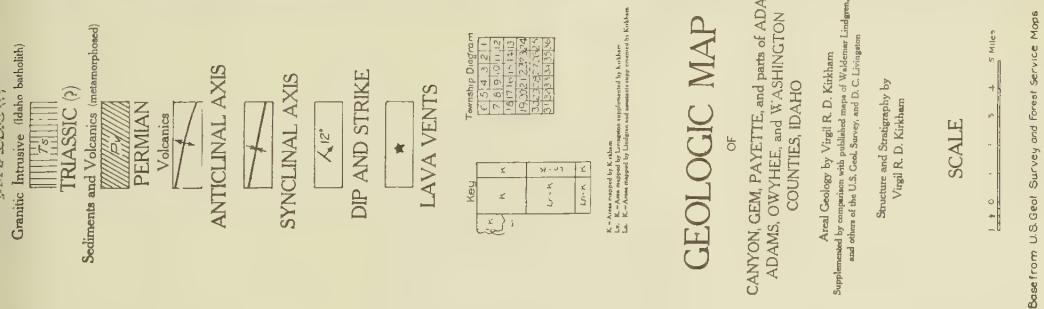


FIG. 1



GEOLOGIC MAP OF CANYON, GEM, PAYETTE, and parts of ADA, ADAMS, OWYHEE, and WASHINGTON COUNTIES, IDAHO

Areal Geology by Virgil R. D. Kirkham
Supplemented by comparison with published maps of Wallace Landings
and others of the U.S. Geol. Survey, and D. C. Livingston

Signature and Stratigraphy by
Virgil R. D. Kirkham

and the basalt is very sketchy, as is also the contact of the volcanics with the Triassic (?) sediments and with the Jurassic (?) granite. Only the roughest of reconnaissances was made in this area, consisting of a single expedition of a few days, undertaken chiefly to determine the nature of the rocks. The lack of a topographic map and the pressure of time prevented the accurate tracing of any boundaries in this mountainous and relatively inaccessible area.

Lithology.—The lowermost series is andesitic. The number of flows is unknown. Agglomerates and tuffs are in places interstratified with the denser lava flows. This andesite is folded into an anticline striking northwest to southeast with dips ranging from 5° to 25° on its axes. The andesite has an apparent thickness of about 7,000 feet where it is cross-cut by the Snake River Canyon. This figure may be excessive if strike faulting, which was unrecognized, has duplicated the beds.

A rhyolite flow or sill, according to Livingston,¹ overlies the andesite. Its thickness is less than 250 feet where examined. It is red stained and has a characteristic outcrop.

Lindgren² showed, on his Plate LXIV, that the northern boundary of this series crosses the Snake at a point in Section 20, about 2 miles north of the south line of T. 13 N., R. 7 W., B. M., and extends southward to Olds Ferry bridge. On his map he classed these rocks as "Juratrias" in age and said that they are "chiefly Triassic lavas altered to greenstones. . . . The lower division consists of greenstones, predominatingly old rhyolites, rhyolite tuffs, and quartz diorite porphyry; it occupies the vicinity of Huntington and the narrow canyon extending for 8 miles north of the place. It is probable that this whole series consists of old surface flows."

Livingston,³ on his Plate I, showed the age of this series to be "Permian (?)," but in his text,⁴ spoke of the "Permian rocks" without appearing to question this age. Livingston⁵ said, "It is impos-

¹ *Ibid.*

² Waldemar Lindgren, "The Gold Belt of the Blue Mountains of Oregon," *U.S. Geol. Surv. 22d Ann. Rept.*, Part 2 (1901), pp. 562-756.

³ *Ibid.*

⁴ Pages 4 and 5.

⁵ D. C. Livingston and F. B. Laney, "The Copper Deposits of the Seven Devils and Adjacent Districts," *Idaho Bur. of Mines and Geol. Bull.* 1 (1920), p. 20.

sible to estimate with any degree of accuracy the thickness of this highly complex series of flows and tuff but it is safe to say that it cannot be less than 10,000 feet and may exceed this figure two or three times."

The Permian age of this series is thought to be established by a collection of fossils made by Dr. F. B. Laney and determined by the United States Geological Survey as a Permian fauna. Mansfield¹ has recognized the Permian age of this volcanic series.

JURASSIC(?) BATHOLITH

All exposures of granitic rocks in the map area, with the exception of a small exposure near Pearl in the Boise Quadrangle, are assigned to the Idaho batholith which underlies an area of at least 16,000 square miles in adjoining portions of the state.

The boundaries of the map area were purposely extended to include the edges of the granite areas which lie near the down-warped basin now filled with lavas and Tertiary sediments. It was thought that a study of the contacts would show whether or not outcrops of sediments, which could possibly act as source rocks for the gasoline-yielding natural gas in the Idaho formation, were present underlying the Columbia River basalt and overlying the granite. No extensive technical study of the granite or its petrographic phases was made because of its lack of bearing on the problem. Its occurrence will consequently be treated briefly in this paper.

Distribution.—There are six localities where granitic intrusions occur:

In the northwestern corner of the Weiser quadrangle and the northeastern corner of the adjoining Huntington area occurs a large mass of granodiorite and diorite which represents the southward extension of a large exposure on Iron Mountain. That part within the map area lies in secs. 1, 2, 3, 10, 11, and 12, T. 13 N., R. 6 W., B. M., and in secs. 5, 6, and 7, T. 13 N., R. 6 W., B. M. A small cupola-like intrusion, less than a square mile in area, has been uncovered in the Snake River Gorge in secs. 6 and 7, T. 12 N., R. 7 W., B. M.

Two large areas of granodiorite, which are westward extensions of the main Idaho batholith, enter the map area in the Squaw Creek sheet and lie chiefly in T. 8 N., R. 1 E., and T. 10 N., R. 1 E. Five small exposures of granitic rock

¹ G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of South-eastern Idaho," *U. S. Geol. Surv. Prof. Paper 152* (1927), p. 186.

crop out in the heads of minor streams which are tributary to Squaw Creek on the east side of Squaw Butte.

Granite and granodiorite exposures in Boise quadrangle lie on the high ridge east of Emmett. These also are western extensions of the main Idaho batholith. The main area is in T. 6 N., R. 1 E., B. M. A small area is exposed in secs. 1, 2, 3, 11, 12, 13 and 24, and other still smaller cupola-like masses crop out in secs. 20, 24, 25, 28, 29, 32, 33, 34, 35, and 36, T. 7 N., R. 1 E., B. M.

Two small areas along the south edge of the map area are northern extensions of the larger mass shown on the geologic sheet of the Silver City Folio.¹ They are located in T. 1 S., R. 3 W., and T. 1 S., R. 4 W., B.M.

Characteristics.—The granodiorite south of the area, as well as on the Boise Ridge, is markedly sheeted and fractured and is in places heavily covered by sandy débris resulting from disintegration. According to Lindgren,² the granite is coarse-textured, gray biotite granite, and contains large crystals of orthoclase. According to Piper,³ it is "characterized by a great abundance of quartz, and small amounts of biotite and muscovite. There is a decided tendency toward porphyritic texture, phenocrysts of potassic feldspar attaining here and there a maximum dimension of $1\frac{1}{4}$ inches."

Lindgren⁴ said that the Silver City phase is more acid than the Boise phase which he describes in *Folio 45*.⁵

In both the Silver City and Iron Mountain localities, dioritic phases are common. In each locality there are marked variations in the amounts of biotite, quartz, and feldspars. Muscovite appears to be always present, but the biotite has decomposed to chlorite in most cases. The plagioclase crystals are small and rarely show Carlsbad twining. Pegmatite dikes and granodiorite porphyry dikes several hundred feet wide are common in the Silver City granite and in the Boise Ridge exposures.

¹ Waldemar Lindgren, "Description of the Silver City Quadrangle," *U. S. Geol. Atlas Folio 104* (1904).

² *Ibid.*

³ A. M. Piper and F. B. Laney, "Geology and Metalliferous Resources of the Region about Silver City, Idaho," *Idaho Bur. of Mines and Geol., Bull. 11* (1926).

⁴ Waldemar Lindgren, "The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts in Idaho," *U.S. Geol. Surv., 20th Ann. Rept., Part 3* (1900), pp. 75-256.

⁵ "Description of the Boise Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 45* (1898).

Age.—Eldridge¹ assigned to the Idaho batholith an Archean age. Lindgren² said, "It has tentatively been referred to the Archean," and, "From analogy with other similar granite areas in Montana and California this intrusion may very likely be assigned to the Cretaceous period."³

In another paper Lindgren⁴ considered the batholith to be post-Triassic in age. At a later date Umpleby⁵ assigned the batholith to the Cretaceous period. This age was accepted by all observers up to 1925, when the writer conceived the idea that the batholith of northern Idaho was part of the Nelson batholith of British Columbia, which is Jurassic in age. The granite in Boundary County was considered by the writer as a connecting link between the Nelson and Idaho batholiths and appeared to be as much a part of one as of the other. Because of this relation, as well as certain philosophic considerations dealing with orogenic disturbances in the Cordillera, the writer⁶ was the first to assign a possible Jurassic age to the Idaho batholith. Ross,⁷ after an extensive survey of the evidence, supported this age assignment in his recent thoroughgoing paper on the subject. He said: "It is reasonable to regard this batholith as one of the products of widespread diastrophism which occurred in the Cordilleran region near the end of the Jurassic period."

Relation to other rocks.—The granodiorite at Iron Mountain underlies Columbia River basalt and has intruded the Permian volcanics at that place. It has also intruded them at the small exposure on Snake River. On the east side of Upper Squaw Creek, the lower

¹ G. H. Eldridge, "A Geological Reconnaissance across Idaho," *U.S. Geol. Surv., 16th Ann. Rept., Part 2* (1894-95), pp. 217-76.

² "Description of the Boise Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 45* (1898), p. 2.

³ *Ibid.*, p. 1.

⁴ "A Geological Reconnaissance across the Bitterroot Range and Clearwater Mountains of Montana and Idaho," *U.S. Geol. Surv. Prof. Paper 27* (1904), p. 20.

⁵ Joseph B. Umpleby, "Geology and Ore Deposits of Lemhi County, Idaho," *U.S. Geol. Surv. Bull. 528* (1913).

⁶ Virgil R. D. Kirkham, "Ground Water for Municipal Supply at Potlatch, Idaho," *Idaho Bur. of Mines and Geol. Pamph. 23* (June, 1927).

⁷ C. P. Ross, "Mesozoic and Tertiary Granitic Rocks in Idaho," *Jour. Geol.*, Vol. XXXVI (1928), p. 692.

Columbia River basalt series rests upon it. Both basalt and lake beds rest on the granitoid rocks south of Payette River. Rhyolite overlies the granite on the east side of Squaw Creek and Owyhee rhyolite, and Payette lake beds rest on the granodiorite south of Crown Point. Payette lake beds, the upper Columbia River basalt series, Owyhee rhyolite, and the Idaho lake beds each rest on the Silver City granite south of the Snake River.

MIOCENE BASALT

COLUMBIA RIVER BASALT

This lava series was referred to by Lindgren¹ as "early Neocene basalt" and given the map symbol of *Nb*. At a later date he² designated it as "early basalt" or "Eocene(?) basalt" and gave it the map symbol of *Tb*. This series is designated on the present map area as *Mb*. In actuality there is an upper and lower series of flows which are separated by several hundred feet of lake beds and terrestrial sediments.³ They are not differentiated on the map area for the sake of simplicity, but will be discussed separately here.

UPPER SERIES

Distribution.—This formation comprises the surface of the greater part of the map area lying north of Payette River and west of Squaw Creek.

Nine relatively isolated exposures of this lava lie south of Payette River in the southeastern part of T. 7 N., R. 1 W., B. M., and in the southwestern part of T. 7 N., R. 1 E. B. M. One of these small outcrops appears to be exposed by erosion of the Idaho formation in Secs. 11 and 12, T. 6 N., R. 1 W., B. M. In the northern part of T. 6 N., R. 1 E., B. M., this lava apparently lies on the Jurassic(?) granite.

Five small exposures occur south of Pearl in the south half of T. 6 N., R. 1 E.,

¹ "Description of the Boise Quadrangle," *U.S. Geol. Survey, Geol. Atlas Folio 45* (1898).

² "Description of the Silver City Quadrangle," *U.S. Geol. Atlas Folio 104* (1904).

³ An upper and lower series of flows has also been recognized in eastern Washington and in central and northern Idaho, as has been pointed out by the writer in several publications of the Idaho Bureau of Mines and Geology as well as in four recent papers of this *Journal*. See pages 489, 491-95, and 490 of "The Latah Formation in Idaho," Vol. XXXVII (1929), pp. 659, 662, and 663 of "Old Erosion Surfaces in Southwestern Idaho," *ibid.*, Vol. XXXVIII (1930); "Revision of the Payette and Idaho Formations," Vol. XXIX (1931), pp. 193-240, "Snake River Downwarp," Vol. XXIX (1931), pp. 456-82.

B. M. The basalt in these exposures overlies granite in places and Payette lake beds in others. One small exposure appears to underlie the Idaho formation in Secs. 23 and 24, T. 5 N., R. 1 E., B. M.

South of Snake River are five relatively small areas of this series which extend into the map area from a much larger exposure of basalt which lies to the south on the Owyhee Mountains. These lie in the northern portions of T. 1 S., Rs. 3, 4, and 5 W., B. M.

Thickness.—The thickness of the upper series is variable inasmuch as it was subjected to an extensive interval of erosion which reduced its surface to a stage of late maturity or early old age before the Idaho formation was deposited. Thus, the thickness of basalt lying between the Payette and Idaho formations probably does not, in any case, represent the original thickness of the upper series.

In many instances subsequent erosion has entirely removed the once overlying Idaho formation and further reduced the thickness of the upper series.

Near Cobb Siding in Secs. 15 and 23, T. 11 N., R. 7 W., B. M., a section exposed chiefly in a syncline (see section *HH*, Figs. 2 and 3) shows 2,185 feet of the upper series overlying the Payette formation.

Near Weiser River, in Secs. 25 and 26, T. 11 N., R. 4 W., a measured thickness of 680 feet of basalt overlies the Payette formation and underlies the Idaho formation. In Secs. 16 and 17, T. 11 N., R. 3 W., B. M., the measured thickness above the Payette is 670 feet. Because the upper lake beds have been eroded, the basalt here probably does not represent the original thickness separating the two lake bed formations.

In Crane Creek Canyon in Secs. 2 and 3, T. 11 N., R. 3 W., B. M., at least 1,000 feet of the upper series remains above the Payette formation. This is on the crest of an anticline and has probably received much erosion since the Idaho formation was stripped off.

In Secs. 25 and 26, T. 10 N., R. 3 W., B. M., a thickness of 445 feet was measured overlying the Payette formation. In Secs. 29 and 30, T. 10 N., R. 2 W., B. M., 730 feet of basalt overlies the Payette. About 450 feet of basalt overlies the Payette formation west of Pad-dock Valley, but a thickness of more than 1,000 feet overlies the Payette on the east side of the valley. Most of this discrepancy appears to have been produced by differential erosion before the deposition of the Idaho formation.

South of Payette River, in the small isolated areas, thicknesses as low as 300 feet separate the Idaho and Payette formations, or the Idaho formation and the granite.



FIG. 3.—Looking north at Payette lake beds, on the left, dipping east under Columbia River basalt on the right, near Cobb Siding.

At Squaw Butte 261 counted flows occur dipping westerly at angles ranging from 8° to 40° (see Fig. 2 and Fig. 4). This massive pile of lava represents a calculated thickness of over 17,000 feet, which probably is to be accounted for by duplication by strike fault-

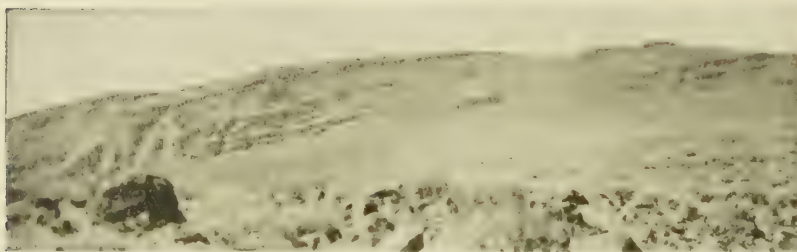


FIG. 4.—Looking north at basalt flows on the summit of Squaw Butte dipping southwest toward the axis of the downwarp.

ing. Although no good field evidence for faulting was found, outside of the steep eastern scarplike face of Squaw Butte, the plotting of flows in a structure section drawn to the same vertical and horizontal scale, using actual dips, indicates notably discordant dips which can logically be explained by one or more gravity strike faults with the downthrown side to the east in each case. Their existence is hypo-

thetical; and proof of their presence, and the dip of the plane and amount of downthrow, await further field studies which will require careful correlation followed by extensive petrographic and chemical analyses. Section *EE*, Figure 2, indicates the dip of the flows and the postulated faults.

Whatever the cause of this great thickening, it overlies the Payette formation and extends northward with a slight decrease for at least 35 miles. This great thickness is exposed in Squaw Butte. The relief between the crest of the ridge and Squaw Creek ranges from 3,000 feet at the southern end to 1,500 feet on the upper part of the creek. The valley of Squaw Creek, of course, rises toward its head, and the ridge becomes lower. The relief on the west side of Squaw Butte is the greatest in the map area. A section across the highest part extends for 8 miles across westward-dipping basalt flows. At the base on the west, the overlying Idaho formation dips westerly at an angle similar to that of the uppermost basalt flow.

A thickness of more than 1,300 feet of this series is exposed in T. 1 S., R. 4 W., B. M., in the region south of Snake River. Piper¹ gave a thickness of 2,000 feet for the region to the south of the map area.

Lithology.—No extensive petrographic study was made of any of the igneous rocks, since it was not pertinent to the economic problems.

The basalt varies greatly in character from place to place. In the region south of Snake River several of the flows are diabasic and show a marked porphyritic character. They are dark in color and contain lathlike phenocrysts of labradorite and grains of olivine, while augite and ilmenite occupy much of the ground mass. In other flows augite and olivine phenocrysts are the most conspicuous. In nearly all instances olivine and augite are prominent in the ground mass.

The upper flows are, as a whole, less porphyritic than the lower ones, although nearly every flow observed showed, at some place, phenocrysts of various sizes chiefly of labradorite, augite, and olivine. Ilmenite grains are characteristic throughout the ground mass. Olivine may or may not be present. Some of the finer-grained types

¹ Piper and Laney, *op. cit.*

exhibit a glassy ground mass, and some of the upper flows contain small needles of feldspar in the ground mass. Piper,¹ in describing these flows in their extension to the south, said that porphyritic types predominate. He spoke of labradorite phenocrysts in an ophitic ground mass interlaced with andesine-labradorite microlites, diallage and ilmenite. He said: "The fine grained phase does not differ markedly in composition and texture from the ground mass of the porphyritic type."

Lindgren,² speaking of the basalt in Boise quadrangle, said: "Although almost all types of feldspar basalt are present, one cannot fail to be struck with the prevalence of coarse, holocrystalline structures, closely approaching diabase to which the name dolerite is applied. . . . The rock is medium grained and vesicular, consisting of lath-like labradorite, brownish augite, and reddish-brown olivine. Between the grains lies a little dark glass."

Attitude and structure.—South of Snake River the Columbia River basalt dips gradually to the north and northeast under the Payette beds which, in turn, underlie the Owyhee rhyolite toward the axis of the Snake River downwarp (see Fig. 5). Lindgren³ showed by his text and structure sections *AA* and *BB* in the Silver City folio that he believed the rhyolite to underlie the lake beds and the tuff (determined by the writer to be no different from the lake beds)⁴ to underlie the basalt.

The scattered exposures of basalt in the Pearl and Montour areas dip toward the west and southwest at angles of 5° to 7°. South of Montour the lava dips from 12° to 19° to the southwest. West of Montour occur dips of 11°, 14°, and 15° to the west.

In the region west of Squaw Creek the flows dip to the west and southwest at angles ranging from 40° to 15°, where the basalt extends under the Idaho formation (see Figs. 2, 4, 6, and 7).

From T. 9 N., R. 2 W., northward the basalt is folded into a series

¹ *Ibid.*, "Geology and Metalliferous Resources of the Region About Silver City, Idaho."

² "Description of Boise Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 45* (1898), p. 2.

³ "Description of the Silver City Quadrangle," *U.S. Geol. Atlas Folio 104* (1904).

⁴ Virgil R. D. Kirkham, "Revision of the Payette and Idaho Formations," *Jour. Geol.*, Vol. XXXIX (1931), p. 219.

of plunging, parallel, asymmetric folds, the largest of which extend beyond the limits of the map area. Some of these folds are more than 30 miles long and several miles in width. Dips as steep as 25° are found on the flanks of the anticlines; and one syncline in T. 11 N., R. 7 W., shows dips of 35° on its flanks. The relations of these folds are shown on the Weiser quadrangle and the Huntington area (see Figs. 1 and 2).

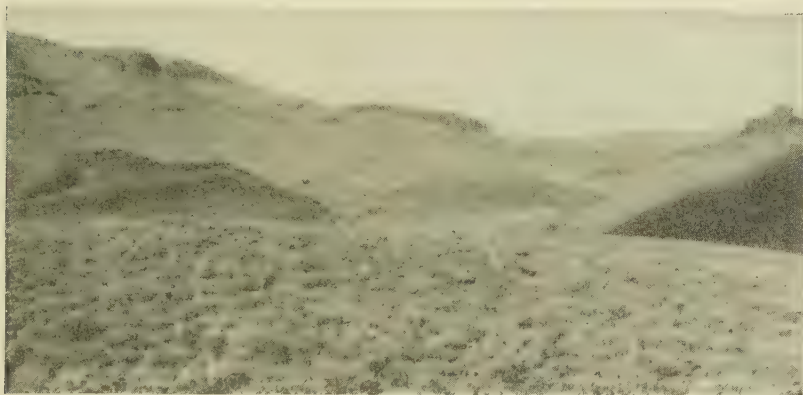


FIG. 5.—Looking north on Little Squaw Creek at the Owyhee rhyolite overlying the Payette lake beds in the middle, and Columbia River basalt underlying the Payette in the foreground.

LOWER SERIES

Distribution.—All of the basalt underlying the Owyhee rhyolite south of the down-warp may belong to the lower series; two small outcrops which are separated from an upper series of flows by a few hundred feet of tuff and lake beds are thought certainly to belong to the lower series. These are situated in the gorges formed by the headwaters of Hardtrigger Creek in T. 1 S., R. 4 W., B. M.

The largest exposure in the area lies north of Payette River and east of Squaw Creek in T. 7 N., R. 1 E., and the eastern part of T. 8 N., R. 1 E. The basalt flows in the eastern part of T. 9 N., R. 1 E., are tentatively placed in the lower series because they dip westward at angles of 5° to 12° under a lake bed series assigned to the Payette formation.

An area of about 5 square miles is exposed in the crest of an anticline east of Weiser River in T. 12 N., R. 4 W., B. M., T. 11 N., R. 4 W., B. M., and T. 11 N., R. 3 W., B. M. This lava series is overlain on the flanks of the fold by the

Payette formation which is, in turn, overlain by the upper series of Columbia River basalt. A small exposure occurs in the bottom of Crane Creek canyon a few miles to the east.



FIG. 6.—Looking north at Squaw Butte in the distance. Basalt flows are shown across Payette River, dipping toward the plain.



FIG. 7.—Looking north along the strike of the Idaho beds overlying Columbia River basalt at Black Canyon dam.

Thickness.—East of Squaw Creek this series is 1,200 feet thick and shows sixteen flows. Not more than 400 feet are exposed at any other locality because the full thickness is not revealed by erosion.

Characteristics.—In so far as field observation could show, this series differs from the upper series in lithology and structure no more than the individual flows of each series differ from one another.

MIocene (?) OR PLIOCENE (?) GRANITIC INTRUSIVE

This igneous rock is the same as that mapped on the geologic sheet of Boise folio by Lindgren¹ under the map symbols of *di* and



FIG. 8.—Payette formation dipping steeply to the south from contact with intruded Tertiary granite, near Horseshoe Bend.

hp. These he called diorite and quartz hornblende porphyry. He considered the material to be two separate dike intrusions and gave them a pre-Neocene age.

Only a small part of the exposure occurs in the map area in T. 6 N., R. 1 E., B. M., northeast of Crown Point. Outside the map area² this granite is found to be intruded into the Payette sediments and the Columbia River basalt. Where it has invaded the Payette formation, the lake beds are highly metamorphosed, and dip quaquaversally from the areas of intrusion (see Figs. 8 and 9). The evidence is conclusive that this intrusive is younger than the Payette formation

¹ "Description of the Boise Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 45* (1898).

² This intrusion is found in the following sections beyond the map area; Secs. 4, 5, and 8, T. 7 N., R. 3 E.; Secs. 21, 22, 23, 26, 27, 28, 29, 31, 32, 33, and 34, T. 7 N., R. 2 E.; Secs. 4, 5, and 6, T. 6 N., R. 2 E., B. M. The Payette sediments are intruded and metamorphosed in Secs. 23 and 26, T. 7 N., R. 2 E. All of these areas are shown on the Boise folio.

and the lower basalt series, which are of Middle or Upper Miocene age. It may be late Miocene or early Pliocene in age.

An examination of twenty or more thin-sections by Mr. M. Melville Johnson, of the University of Idaho, showed that the mass is generally a normal granodiorite; all exceptions were more acidic in character. A porphyritic texture is caused by pink feldspar phenocrysts. This texture is characteristic of the entire exposure.



FIG. 9.—Payette formation dipping steeply to the northeast from contact with Tertiary granite. Position of bedding planes indicated by drawn lines.

UPPER MIOCENE (?) OR LOWER PLIOCENE (?) RHYOLITE

OWYHEE RHYOLITE

This name is given to an acidic lava series, outcrops of which were called "Neocene rhyolite" and "Tertiary rhyolite" by Lindgren.¹ His map symbols are *Nr* and *Tr*. The writer uses the symbol *Pr* for the exposures in this area. This rhyolite series is part of a very extensive acidic sheet which underlies the Snake River down-warp throughout Idaho and extends, in scattered erosional remnants, over great areas in the regions bordering the down-warp, reaching into Utah, Nevada, Montana, and Wyoming. Descriptions of its occurrence elsewhere are found in former papers of the writer,² where they are referred to as "Tertiary late lavas." This

¹ *Op. cit.*, "Description of the Boise Quadrangle," "Description of the Silver City Quadrangle."

² Virgil R. D. Kirkham, "A Geologic Reconnaissance of Clark and Jefferson and Parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho," *Idaho Bur. of*

lava series, once widespread at the surface, now outcrops as a ragged fringe bordering the Snake River basalt, where it has remained unburied; or it is revealed where recent erosion has cut through the younger basalt and exposed it in stream canyons. It also appears in minor arched-up areas where it was never completely covered with basalt or where the basalt has been almost entirely removed by erosion.

Along the northern side of the plain, exposures represent erosional remnants on the noses of plunging structural ranges. These remnants dip beneath the Snake River basalt. In the valleys separating the ranges, the upper edge of the acidic series has been removed by erosion, but is shown by well logs to extend across the valleys beneath the overburden of later gravels and basalt.

The eastern third of the Snake River plain has an uninterrupted border of the rhyolite series which swings around the northwest, north, east, and southeast flanks of the downwarp. On the southeast side it appears also on the noses of the plunging ranges and in erosional remnants on their crests. It also extends for many miles into the structural depressions which lie between the ranges.

These lavas characteristically dip toward the long axis of the down-warp on all sides, with angles ranging from 2° or 3° up to 10° . This dip is often the surface slope and nearly always closely approximates it. Erosion has removed the Snake River basalt in a large number of places in the eastern plain area and revealed the lower-lying acid lava series. These occurrences offer persuasive evidence for believing that a widespread sheet of rhyolite lavas now extends, or formerly extended, under the later basalts and lake beds which now partially fill the present depression.

Mesa-like lava caps on high peaks bordering the plain indicate that this blanket-like series of acid lavas once had an extent far greater than the present widespread Snake River basalts of the Snake River plain.

Interbedded with this series or underlying it, there are found, in many places, bedded continental deposits which are conformable

Mines and Geol. Pamph. 19 (January 1927); "Geology and Oil Possibilities of Bing-ham, Bonneville and Caribou Counties, Idaho," *Idaho Bur. of Mines and Geol. Bull.* 8 (1924); "Snake River Downwarp," *Jour. Geol.*, Vol. XXXIX (1931), pp. 456-82.

and tilt, as do the lavas, toward the axis of the Snake River plain down-warp. The formation was described and called the Salt Lake formation, by Mansfield.¹ It was given, tentatively, a Pliocene age. Although no definitive flora or fauna has as yet been determined from the Salt Lake formation, its field relations, especially with the rhyolite series, suggest that it may be comparable in age and origin to the Payette formation of southwestern Idaho, and may eventually be assigned an Upper Miocene age. The conformable relationship of this formation and the lava series has been previously described for some of the area south of the plain, by the writer. The tilted ash beds, tuffs, conglomerate, limestone, etc., which make up this formation, convince the investigator that the conformable lavas which lie above, and in some places below, the series are not flow slopes like the slopes of the great broad-based cones of later basalt to be observed out in the plain. At the Continental Divide, in the Centennial Range, the same flows which pass over the range at an elevation of 10,000 feet, pass under the plain basalt flows at an elevation of about 6,000 feet. The difference in elevation is nearly as great on the ranges south and southeast of the plain, but is less toward Yellowstone National Park on the east. Since this much difference in elevation exists above the present basalt lava of the plain, a considerable relief must be allowed for, with the extension of this series under the plain.

Sections made in the eastern part of the Snake River plain show that the series is generally made up of basal flows of basalt and andesite, with trachytes, latites, and rhyolites constituting the upper flows. Interbedded with these lavas occur ash beds, fresh-water limestone, clay, shale, sandstone, and conglomerate, which are called the Salt Lake formation, southeast of the plain.

One section on Snake River in southeastern Idaho shows at the base calcareous conglomerate of the Salt Lake formation; thickness unknown. This is overlain by 35 feet of latite. This in turn is overlain by 25 feet of black to dark-green vesicular basalt. Next comes 35 feet of pink rhyolite, tuff, and agglomerate. Above this occurs 100 feet of a conglomeratic deposit cemented by pink volcanic ash

¹ G. R. Mansfield, "The Wasatch and Salt Lake Formations of Southeastern Idaho," *Amer. Jour. Sci.*, Vol. L (July, 1920), pp. 54-64.

in some places, and by travertine spring deposits in other localities. Rounded pebbles of variegated country rocks are found within this matrix. Succeeding this is a red trachyte, a red andesite, and a gray rhyolite. This section is about 250 feet thick. Over it all rests Snake River basalt.

At one place north of the plain, more than half the section is old basalt, but a few flows of andesite and rhyolite, separated by acidic tuff, make up the top of the series. At this place, much of the upper part is eroded, leaving a fairly large area of the older basic material exposed.

At another place one basalt flow and several andesites make up the base of the column. On the gently sloping benches bordering this exposure, appear higher uneroded flows of latite and rhyolite which apparently top the series here.

Most of the Centennial Range is covered at the surface with rhyolites, latites, and trachytes. The lower-lying andesites are exposed mainly in the stream valleys and cliffs.

The Tertiary late lavas appear to have occurred in widespread flows, many of which were observed to have areas of at least 100 square miles. Along the entire Centennial Range, only one source was recognized.

Flows in the eastern part of the plain undoubtedly belong to the widespread westward-extending sheets of Yellowstone National Park. It may be that a great part of the lava in the plain owes its origin to this source. Southeast of the Snake River plain about a dozen old, but relatively small, acidic lava and tuff cones have been recognized. These, of course, would suggest a manner of distribution of the acid lavas very similar to that of the Snake River basalt. Six flows with an average thickness of less than 50 feet each were noted at several places in this series.

Distribution.—

In the map area the rhyolite is found in one large exposure south of the down warp, and three smaller ones on the north side. South of Snake River it occurs in T. 2 N., R. 5 W., T. 1 N., R. 5 W., T. 1 N., R. 4 W., T. 1 N., R. 3 W., T. 1 S., R. 5 W., T. 1 S., R. 4 W., and T. 1 S., R. 3 W., B. M. This is the northern extension of the great rhyolite sheet mentioned above which covers most of Owyhee County to the south. A small part of it is shown on the geologic sheet of Lind-

gren's¹ Silver City Folio. A small exposure occurs in T. 6 N., R. 1 E., and also in Secs. 3 and 4, T. 5 N., R. 1 E., and Sec. 25, T. 6 N., R. 1 W., B. M. The latter exposure is revealed by the erosion of the overlying Idaho formation and indicates that the rhyolite underlies a considerably greater area than that occupied by its outcrop. A small part of an extensive exposure is included in the map area in the northeastern part of T. 8 N., R. 1 E., and in the southeastern part of T. 9 N., R. 1 E.

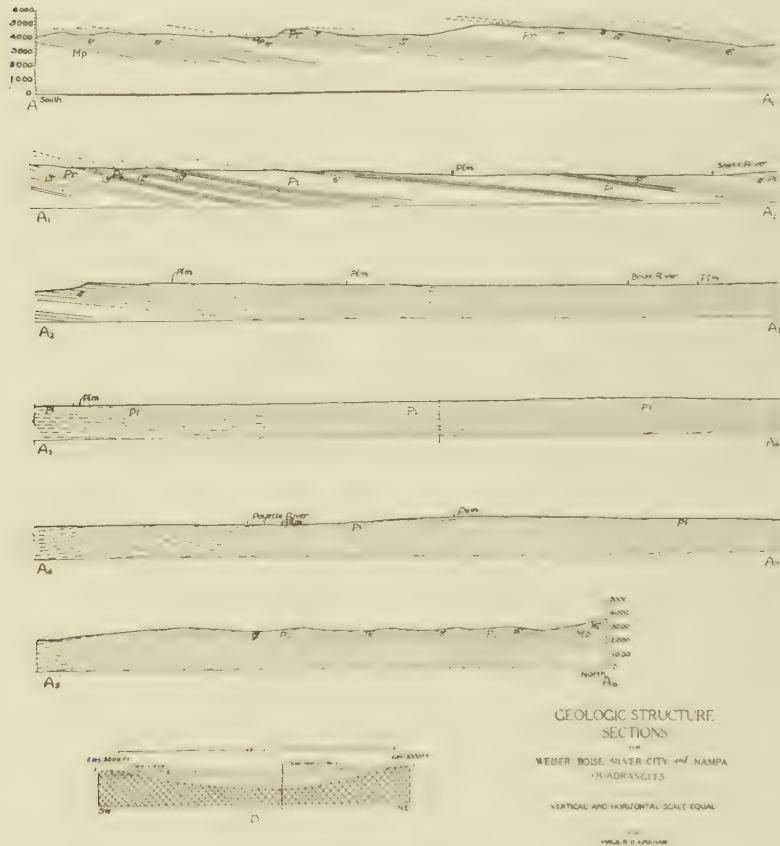


FIG. 10.—*Mp* is the Payette formation, *Pr* is the rhyolite series, *Pi* is the Idaho formation, *Plm* is the Lower Mesa formation, and *Pim* is the Upper Mesa formation. *Mb* is Columbia River basalt.

Thickness, lithology, and attitude.—A measured thickness of over 1,850 feet of rhyolite is exposed in Little Squaw Creek Canyon east

¹ "Description of the Silver City Quadrangle."

of French John Hill. At several places 1,500 feet of rhyolite are exposed without revealing the entire thickness. In the southern part of T. 1 N., R. 5 W., the flows dip at angles of 3° to 5° to the north and northwest. In the northern part of the township the dip gradually steepens to 8° , 10° , and 11° to the northeast (see Figs. 1, 2, 5, 10, and 11). In T. 2 N., R. 5 W., the dip steepens to 15° and 16° to the northeast. At several places in T. 1 N., R. 4 W., dips of 15° to the northeast are encountered.

The general dip is toward the down-warp axis, and is generally gentle at some distance from the plain but gradually steepens until it plunges under the lake beds of the Idaho series (see Figs. 1 and 2).

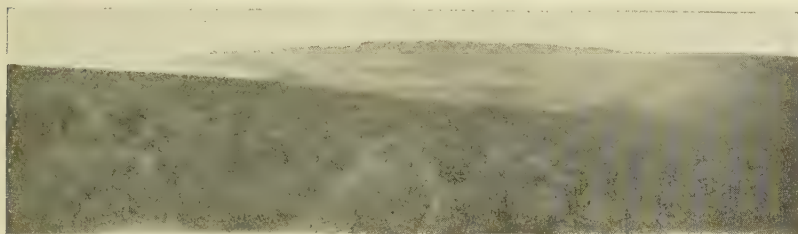


FIG. 11.—Looking west at an intermontane valley near Rockville. The foreground is underlain by Payette formation. The higher land in the distance is composed of overlying Owyhee rhyolite flows.

At places the rhyolite certainly overlies the Payette lake beds without angular unconformity. At one or two places the lake beds appear to dip more steeply than the rhyolite. This, of course, is not certain because the dip in lava flows is more obscure than that of the bedding planes of the sediments.

At the Pearl area the rhyolite also underlies the Idaho formation and dips with the lake beds southwesterly to the axis of the down-warp at angles of 4° to 7° . The series here has been eroded until a thickness of only 200 feet remains.

East of Squaw Creek in T. 9 N., R. 1 E., B. M., the rhyolite overlies the lower series of the Columbia River basalt, as well as the granite. It dips to the west at the low angle of 5° . Over 700 feet of rhyolite is exposed in this locality, although much erosion has removed some of the original thickness. The following descriptions of acid rock collected by the writer from outside the map area are based

on petrographic studies made by Professor Alfred L. Anderson, of the University of Idaho. About 100 rock types were studied and the following descriptions were chosen to represent typical occurrences over a wide area:

One rhyolite characteristic of the acid types of this series is pale lavender to mauve in color. A layered fluidal structure is caused by alternating deep lavender, dense and stony bands, and cream-colored porous bands of feldspar and quartz. Glassy phenocrysts of oligoclase are present in both bands. More crystalline quartz occurs in this type of rock than in the other acidic types. It is generally in lenslike seams in the light-colored porous bands. Biotite is recognizable. About 90 per cent of the rock is a microspherulitic ground mass estimated to contain 66 per cent orthoclase and 22 per cent quartz. Phenocrysts of oligoclase polysynthetically twinned make up 2 per cent. The cream-colored bands of quartz and feldspar make up 8 per cent of the rock. The orthoclase formed first and is surrounded by anhedral quartz. It appears that the lava cooled very rapidly, permitting a microspherulitic mass to form with cavities and vesicles filled with aqueous solution of orthoclase and quartz, residual juices, to crystallize slowly. Biotite constitutes 2 per cent of the mass, but was originally more abundant. Hematite developed from the biotite gives the rock its color. Magnetite makes up two per cent of the total.

The trachytic type of rhyolite, the most common in the series, contains no observable quartz. The rock is dense, slightly porphyritic, and of a pinkish cream, or lavender, color, with faint fluidal structure. The rock rings like phonolite when struck. Infrequent phenocrysts of dull white oligoclase comprise less than 1 per cent of the mass. Altered hornblende crystals are accessory.

The ground mass is eutaxitic and cryptocrystalline, and apparently chiefly orthoclase. The texture is that of a rhyolite; and, although quartz could not be identified, its presence is inferred from this texture. This rock also has lenses filled with orthoclase probably crystallized from a slowly cooling solution in cavities of a quickly chilled magma. Magnetite and hematite are unimportant accessories.

Another trachytic type of rhyolite is darker lavender with more pronounced fluidal structure. The weathered lava possesses knotty seams, and ridges in high relief, like the bark of yellow pine. It also rings when struck. Its phenocrysts are orthoclase and sanidine. No quartz is observable, and the rock is less acid than the preceding one. Nevertheless, it is called rhyolite because of the texture.

A dark-gray rhyolite which is generally present in the area is highly vesicular. The cavities are often several inches long and an inch across. Flow structure is dominant and fine lines of lavender alternate with black glassy bands. Sanidine crystals are abundant. They are glassy and lathlike forms, and the fluidal lines curve around them. They comprise 4 per cent of the rock and are characterized

by a notable cleavage. The seams and cavities in this rock are lined with sub-hedral orthoclase crystals, indicating that after the main mass had quickly cooled these cavities retained aqueous solutions which crystallized slowly. Hematite has formed from hornblende. No quartz is observable, but the texture is that of a rhyolite.

A latite porphyry, little different from the other types described, contains more hornblende, due perhaps to slower cooling conditions. The color is lavender, but no flow lines show. About 80 per cent of the phenocrysts are andesine and 20 per cent hornblende. The groundmass is 55 per cent orthoclase, 5 per cent quartz, and the rest glass. Magnetite, hematite, and biotite are accessories; and the hornblende is rich in iron.

Lindgren¹ said,

Porphyritic crystals are represented by small sanidines, and by occasional, though not abundant, quartz grains. Biotite is seldom noted, although partially resorbed crystals of that mineral are sometimes seen under the microscope. The groundmass is nearly always cryptocrystalline, is frequently filled with small spherulites, and shows a banded structure of alternating lighter and darker brownish streaks. Pure rhyolite glass occurs in specimens from the small area 4 miles east of Dewey. More rarely is the rhyolite microcrystalline in structure. Rock of this type is found in the small area 4 miles east-southeast of Rockville. Its appearance, owing to the dark color of the rock and its dense texture, is not unlike that of certain basalts. This variety contains a few larger orthoclase crystals, smaller and rounded grains of andesite in a groundmass of feldspar grains, and microcrystalline quartz.

The rhyolite north of the plains is similar in character. Bryan,² in describing the same series in a nearby area, said,

The porphyritic rhyolite is massive, is marked by strong flow lines, and has the conchoidal fracture and brittleness of lavas of the rhyolite group. The main body is prevailing red and is speckled with feldspar phenocrysts, but in places in this mass the rock is dark gray or black. . . . The absence of noticeable quartz phenocrysts and the glassy character of the ground mass made classification difficult.

He divides the porphyritic rhyolite into four phases, unlike in appearance but similar in composition, namely, red felsite, felsite breccia, pitchstone, and pitchstone agglomerate. He said,

¹ "Description of the Silver City Quadrangle," p. 4.

² Kirk Bryan, "Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon," *U.S. Geol. Surv. Water-Supply Paper 597-A.*, (Jan. 1929), p. 44.

The red felsite is a massive aphanitic rock of a dull red to magenta here with colorless feldspar phenocrysts. . . . The phenocrysts are seen to consist of calcic andesine ($\text{Ab}_{45}\text{An}_{55}$) and there is in small quantity a mineral of high birefringence that seems to be augite. Many slides show no quartz . . . The ground mass is generally glassy with a considerable amount of microcrystalline calcic feldspar.

It is obvious from the foregoing description that the acidic sheet which occurs extensively throughout southern Idaho possesses unusual characteristics which are common over its entire area. There is no question in the mind of the writer that the Owyhee rhyolite is the same series as Bryan's¹ "porphyritic rhyolite," and that both are parts of the Tertiary Late Lava series described by the writer² in *Pamphlet 19*.

PLIOCENE AND PLEISTOCENE BASALT

SNAKE RIVER BASALT

Several thin, slightly tilted, basalt flows occur interbedded with, or overlying, the Idaho formation in parts of Boise, Bisuka, Nampa, and Silver City quadrangles. These flows represent the westernmost extensions of a vast area of Snake River basalt which covers the lake beds to the east and extends to Yellowstone Park, and at places partly fills the basin formed by the Snake River downwarp.

Russell³ said,

The name Snake River lava is here proposed as a general term by which to designate the basaltic rocks that underlie by far the greater part of the Snake River plains, and to a great extent form their actual surfaces. . . . In certain localities in the west portion of the Snake River plains lava sheets are more or less completely covered by sedimentary deposits. . . . The change is gradual from where the lava is the most prominent surface feature in southeastern Idaho to where, at the west, sedimentary deposits greatly predominate.

The occurrence in other parts of the down-warp has been discussed by the writer⁴ in former papers. In *Pamphlet 19* he said,

This type of lava rock, commonly called the Snake River basalt, appears everywhere as the surface lava in the plain area. At some places it is covered

¹ *Ibid.*

² *Op. cit.*

³ I. C. Russell, "Geology and Water Resources of the Snake River Plains of Idaho," *U.S. Geol. Surv. Bull.* 199 (1902), p. 59.

⁴ Virgil R. D. Kirkham, "A Geologic Reconnaissance of Clark and Jefferson and Parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho," *Idaho Bur. of Mines and Geol. Pamphlet 19*; also *Idaho Bur. of Mines and Geol. Bull.* 8.

with an overburden of gravel or soil and at others it has been eroded so as to reveal lower lying lavas of another series.

The basalt does not extend as embayments in the valleys, as has been said of this area. No Snake River basalt extends into the valleys on the northeast or northwest of the plain.

Basalt flows do, however, occupy some of the valleys which enter the plain from the southeast. These valleys lie outside the mapped area and in all instances the basalt does not represent embayments, but flows which have originated in the upper part of the valley and flowed toward the plain. At some places the flow joined the basalt of the plain and at other places failed to reach that far. This valley basalt, because of its lithology and relationship to the underlying formations, is assigned the same age as the lava in the plain.

Most of the cones have volcanic necks of diabase, and the craters contain much scoria, but the flows vary greatly in texture from fine-grained stony rock, to vesicular and porphyritic types. The basalt is generally a heavy dark gray to black rock which contains varying amounts of olivine, magnetite, and labradorite. No specimen can be described which is typical of any great area. More than 100 different flows of about 20 different ages were noted. At no place was a flow more than 15 miles long, or covering an area greater than 125 square miles, seen in the Snake River basalt area. A few lava cones have extruded flows covering areas from 75 to 100 miles in area. The greater number, however, are much smaller and represent only a few square miles. The thickest flows observed were no more than 50 feet and most of them appear to be much less in thickness. At no place were widespread lava sheets, similar to those of the Columbia River lava, recognized. A possibility exists that earlier and basal flows may have been extruded from fissures and were more widespread than those showing at the present surface.

Distribution.—

In the map area the Snake River basalt occurs in Tps. 1 and 2 N., R. 1 E., T. 1 S., R. 1 E., and Tps. 1, 2, and 3 N., Rs. 1 and 2 W. Three small areas separated from the main flow by river planation lie near Caldwell in T. 4 N., R. 3 W. This is the westernmost exposure of Snake River basalt in Idaho. Another exposure of an upper flow lies in T. 2 N., R. 3 W., near the top of Pickles Butte. A small remnant of the western flow lies in sec. 36, T. 3 N., R. 4 W. A lower flow crops out in the northeast wall of Snake River Canyon in T. 1 S., R. 2 W., T. 1 N., R. 3 W., T. 2 N., R. 3 W., and T. 2 N., R. 4 W., B. M.

Thickness and extent.—The flows in this area are parts of a widespread sheet which, according to Russell,¹ extends, "in the neighborhood of 20,000 square miles," and is credited by him as the second

¹ *Op. cit.*

largest lava field in North America. Two separate sheets occur in the Silver City quadrangle, which average about 25 feet each in thickness. The flow in Nampa quadrangle varies from 15 to 50 feet in thickness. Several flows in the Bisuka area represent a much greater but unknown thickness. The Snake River Canyon, at places east of Buhl, shows a thickness of 700 feet of Snake River basalt.

Wells in the plains area of Butte County to the east of the map area have penetrated more than 1,000 feet of this lava series.

Lithology. At all places the basalt is less weathered and usually more fine-grained than Columbia River basalt. It is a heavy, dark gray to black rock which contains greatly varying amounts of olivine, magnetite, and labradorite. Both in megascopic and microscopic analysis it is easily distinguished from Columbia River basalt by texture and composition.

Origin.—In the map area the basalt flowed from cones and central vents which are indicated by a star-shaped map symbol (see Fig. 1).

In the neighborhood of Kuna are seven local sources from which the lava was quietly extruded. Lying in the northern half of T. 1 N., R. 1 W., B. M., with its crest in Section 10, rises a great lava mound which represents one of the highest lava cones found anywhere in the Snake River plain.

This cone rises over 600 feet above the surrounding plain and covers an area of about 11 square miles. Minor vents are located on its sides. Another important cone lies in Section 20. Initial Point is also a source of eruption. East of Walters Butte, in Secs. 10 and 15 T. 1 S., R. 2 W., occur three small eruption centers from which much ash and tuff as well as lava have been ejected.

The Pickles Butte area has three vents from which flows have originated. They lie in Secs. 22, 23, and 29, T. 2 N., R. 3 W.

Two small basalt plugs from which flows may have extended are located in Sec. 35, T. 3 N., R. 4 W. A small lava remnant in Section 36, appears to have been extruded from one of these. Three practically circular basaltic plugs occur in T. 1 N., R. 40—one lies in Section 12, the others are in Section 13. Five plugs occur in T. 1 N., R. 3 W., with two in Section 18, two in Section 19, and one in Section 29. Two plugs occur in Sec. 9 T. 1 S., R. 3 W. One plug lies in Sec.

24, T. 2 N., R. 4 W., B. M. Two plugs in Secs. 18 and 19, T. 2 N., R. 3 W., have apparently been the source of part of the lower flow in the Snake River Canyon.



FIG. 12.—Basalt sill intruded into the Idaho formation east of Marsing and the Snake River. Nearly all of the overlying Idaho sediments have been removed by erosion.

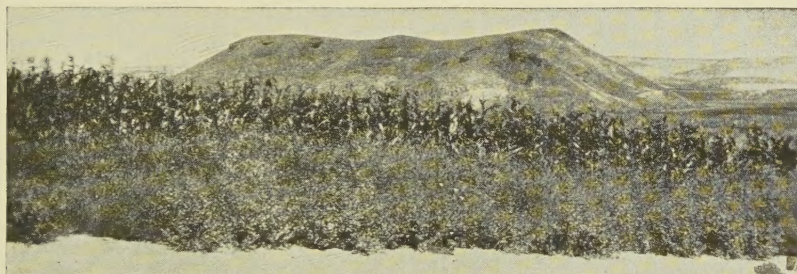


FIG. 13.—Basalt plug east of Snake River in the Silver City quadrangle; typical of those intruded into the Idaho formation.

MODES OF OCCURRENCE

The Jurassic(?) granodiorite and Miocene(?) granodiorite occur as batholithic intrusions. These are accompanied by pegmatite, aplite, lamprophyre, and basalt dikes. At least one sill was recognized where Snake River basalt lies intercalated in Idaho sediments. This occurs about 2 miles east of Marsing and Snake River (see Fig. 12). Outside the area one exposure of Miocene granite has a laccolithic relation where it arches up the Payette sediments. Many plugs

occur and were, in some cases, feeders to flows now removed by erosion. In other cases they may never have reached the surface until exposed by erosion (see Fig. 13).

The Permian volcanics consist of flows, agglomerates, tuff, and breccias. The Columbia River basalts include minor tuffaceous layers interbedded with flows. The Owyhee rhyolite contains some agglomerate and tuffaceous phases with massive flows. The Snake River basalt occurs chiefly in this area as flows and plugs, but is accompanied by much lapilli in some localities. Outside of the area to the east are many cinder cones.

SUCCESSION OF IGNEOUS ACTIVITY

Explosive volcanic activity marked the period of extrusion of the Permian volcanics which may have extended into the Triassic. Coincident with the intrusion of other western batholiths, occurred the Idaho batholithic intrusion, probably in the late Jurassic.

In the Middle or Upper Miocene occurred the extrusion of the first flows of Columbia River lava. After a period of quiescence, there occurred the second extrusion of Columbia River lava in Upper Miocene time.

The Miocene or Pliocene granodiorite intruded the Columbia River basalt and Payette lake beds, and the Owyhee rhyolite was probably extruded at about the same time or a little later. These two events may have occurred at the close of the Miocene, rather than in the Pliocene, because they were succeeded by a period of erosion now expressed by a notable disconformity. Some of the Snake River lava outside the map area to the east may be Pliocene, but much of it is more certainly Pleistocene in age. In the area farther east flows have occurred probably within the last few hundred years.

